

**AN INVESTIGATION INTO THE ADVANTAGES OF A TWO SEAT
TRAINER AIRCRAFT FOR INITIAL V/STOL PILOT TRAINING**

A Thesis

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DEDICATION

This thesis is dedicated to all of the V/STOL flight instructors that have endeavored to teach new pilots about the unique and sometimes dangerous aspects of V/STOL flight.

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ABSTRACT

This research attempted to define the advantages of using a two-seat trainer aircraft for conducting initial Vertical/Short Take-Off and Landing (V/STOL) pilot training. Several driving factors support this concept. First, the design of aircraft and flight controls for the V/STOL environment is unique. Second, the tasks performed by V/STOL aircraft are similarly unique, and differ considerably from conventional aircraft. Third, the characteristics of the slow speed flight regime require a level of visual and motion fidelity not currently available in flight simulators. Finally, when the aircraft is operating in the V/STOL environment very little time is available for corrective action and/or ejecting from the aircraft if a dangerous situation develops. This makes close instructor supervision, available only in a two seat aircraft, even more important. Comparisons between simulator and actual flight were analyzed, along with capabilities and limitations of a variety of modern flight simulators. A review of V/STOL history, aircraft design, unique tasks, and current flight training methodology was conducted to show that V/STOL flight presents unique challenges and dangers that demand safe and effective training methods. Advances in V/STOL technology were examined for their effect of reducing the difficulties associated with V/STOL flight.

It was concluded that despite all efforts to make future V/STOL aircraft safer and easier to fly, initial exposure to the slow speed and hovering flight environment would remain high risk. This requires near immediate instructor input and the option for possible intervention achievable only in a two seat aircraft.

TABLE OF CONTENTS

INTRODUCTION.....	1
CHAPTER I.....	4
HISTORICAL PRECEDENTS	4
General	4
YAK-38/YAK-141.....	4
Harrier	5
Reducing Mishaps	7
F-22B Development	9
Other Aircraft Examples	10
CHAPTER II	12
UNIQUE ASPECTS OF V/STOL FLIGHT	12
General ...	12
Flight Controls.....	12
Aircraft Weight	15
V/STOL Flight Tasks	15
Conversion	16
Approach and Landing	17
Take-Off ..	18
Visual Cues ..	20
Motion Cues	22
Winds	23

Jet Effects	24
CHAPTER III.....	26
FLIGHT TRAINING METHODOLOGY	26
Building Block Approach	26
V/STOL Flight Training.....	27
Current AV-8B Training Syllabus	28
Conversion/Refresher Training.....	30
Two Seat Aircraft	31
CHAPTER IV	33
FLIGHT SIMULATORS	33
General	33
Visual Systems	36
Field of View.....	37
Motion Systems	38
Accurate Modeling	41
Degree of Realism.....	44
Simulator vs. Aircraft Comparison	46
Simulator Effectiveness.. ..	47
CHAPTER V	49
ADVANCES IN V/STOL TECHNOLOGY	49
Advanced V/STOL Flight Controls	49
Pilot Protection Features	51

VAAC Research	52
CHAPTER VI.....	55
RISK MITIGATION THROUGH USE OF TWO SEAT TRAINERS	55
Task Training Survey	57
CHAPTER VII	60
CONCLUSIONS AND RECOMMENDATIONS	60
REFERENCES	Error! Bookmark not defined
APPENDIX	69
VITA.....	81

LIST OF TABLES

TABLE 1-1 MISHAP RATES.....	8
TABLE 2-1 TASK COMPARISON FOR LANDING.....	19
TABLE 2-2 TASK COMPARISON FOR TAKEOFF.....	21
TABLE 3-1 CURRENT HARRIER TRAINING SYLLABUS BREAKDOWN ...	29
TABLE 3-2 HARRIER REFRESHER SYLLABUS.....	31
TABLE 4-1 SIMULATOR FIELD OF VIEWS.....	38
TABLE 4-2 NASA AMES VMS MOTION SYSTEM PERFORMANCE LIMITS	40
TABLE 4-3 LOCKHEED MARTIN TACTICAL AIRCRAFT SIMULATOR MOTION SYSTEM PERFORMANCE LIMITS	40
TABLE 4-4 RESULTS OF SIMULATOR TO FLIGHT COMPARISON FOR V-22 SHIPBOARD EVALUATION	47
TABLE 4-5 FACTORS CONTRIBUTING TO LOW BACKWARDS TRANSFER	48
TABLE 6-1 SURVEY RESULTS	58

LIST OF FIGURES

FIGURE 1-1 HARRIER ACCIDENT CAUSAL FACTORS	7
FIGURE 4-1 PILOT FEEDBACK AND AIRCRAFT RESPONSE	35
FIGURE 4-2 SOURCES OF DELAY IN AIRCRAFT SYSTEMS	44
FIGURE 4-3 HEART RATE DURING MISSION TASKS.	45
FIGURE 5-1 APPROACH TO HOVER RATINGS	53
FIGURE 6-1 MISHAPS AS A FUNCTION OF PILOT EXPERIENCE.....	55
FIGURE 6-2 SOURCES OF UNSAFE ACTS	59
FIGURE A-1 HARRIER REACTION CONTROL SYSTEM.....	70
FIGURE A-2 CONVENTIONAL AIRCRAFT LANDING.	71
FIGURE A-3 HARRIER SLOW LANDING	72
FIGURE A-4 HARRIER VERTICAL LANDING.....	73
FIGURE A-5 HARRIER JET INDUCED EFFECTS IN PITCH... ..	74
FIGURE A-6 HARRIER JET INDUCED EFFECTS IN ROLL	75
FIGURE A-7 HARRIER HOT AIR AND FOD REINGESTION	76
FIGURE A-8 HARRIER EJECTION SEAT ENVELOPE	77
FIGURE A-9 NASA AMES VERTICAL MOTION SIMULATOR.....	78
FIGURE A-10 HARRIER RADAR NIGHT ATTACK SIMULATOR.....	79
FIGURE A-11 COOPER HARPER RATING SCALE	80

LIST OF ABBREVIATIONS

AoA	Angle of Attack
ASTOVL	Advanced Short Take-Off and Vertical Landing
CIG	Computer Image Generator
CTOL	Conventional Take-off and Landing
DFCS	Digital Flight Control System
FOD	Foreign Object Damage
IFPC	Integrated Flight and Propulsion Control
NASA	National Aeronautics and Space Administration
RCS	Reaction Control System
STOL	Short Take-Off and Landing
USAF	United States Air Force
USMC	United States Marine Corps
VAAC	Vectored thrust Advanced Aircraft Control
V/STOL	Short Takeoff and Vertical Landing
VMS	Vertical Motion Simulator
V/STOL	Vertical/Short Takeoff and Landing
VTOL	Vertical Takeoff and Landing

INTRODUCTION

Several aircraft in the past 40 years have been developed to operate from places other than standard runways. These aircraft are classified as Vertical Take-Off and Landing (VTOL), Short Take-Off and Landing (STOL), Vertical/Short Take-Off and Landing (V/STOL), Short Take-Off and Vertical Landing (STOVL). The classification is dependent on the aircraft's capability. This report will refer to all of these types of aircraft as V/STOL for simplification.

Historically, military flight training has relied on three primary tools to train student pilots. These are classroom study, flight simulators, and actual aircraft flights. Vertical/Short Take-Off and Vertical Landing (V/STOL) aircraft are no exception to this philosophy. Determining the training requirements for any aircraft is largely based on how easy that aircraft is to operate. Although advances in aircraft technology continue to produce more sophisticated and capable aircraft, it remains to be seen if future V/STOL aircraft will be made easier to operate than those in service today.

Most current military aircraft have two seat variants that allow an instructor pilot to be onboard to demonstrate, evaluate, and supervise a student during task performance. These two seat variants typically have flight controls in both cockpits that allow either the student or instructor to safely operate the aircraft. This provides the instructor with the additional flexibility of being able to intervene and take control of the aircraft if required. The use of two seat trainers has been particularly important for V/STOL aircraft. These aircraft have historically been considered difficult to fly for several reasons. One is their unique capability to operate in the slow speed and hovering flight regime. A second is

that they usually employ flight controls that are not found in conventional aircraft, such as those required to change the thrust vector. Given the exposure to a new flight environment and the hazards associated with it, two seat trainers have been considered necessary for initial pilot training. These aircraft permit close instructor supervision and immediate intervention should a hazardous situation develop

Flight simulators have also played an important part in pilot training. Recent advances in simulator capabilities have led to a greater reliance on these devices for all aspects of pilot training. Simulators offer a safe environment to train for difficult maneuvers, as well provide cost savings over operating actual aircraft. Despite advances in simulator technology, some segments of V/STOL flight training requires a degree of visual and motion realism that is not achievable with current military flight simulators

Pilot training is largely based on a building block approach. This begins with simple maneuvers in simple aircraft and progresses to more advanced maneuvers in more advanced aircraft. In most cases a pilot is first exposed to a task in some type of flight simulator and then performs the task in an aircraft. V/STOL flight training is no exception. As currently implemented in the United States Marine Corps (USMC) AV-8B community, a student undergoes a syllabus that combines academics, simulator, two-seat and single seat aircraft training. Throughout the syllabus the student is instructed how to perform a maneuver, practices the maneuver, and then is evaluated on how well he performs the maneuver. Two seat variants of the aircraft or TAV-8Bs are an integral part of this syllabus.

In some phases of flight, V/STOL aircraft typically utilize flight controls and techniques that can differ significantly from conventional aircraft. In these phases, previous experience in conventional aircraft may be of little value to the pilot beginning V/STOL flight training. Because of the capabilities inherent in a V/STOL airplane, the pilot has a variety of options available for takeoff and landing types that are not available in conventional aircraft. He has the capability to perform rolling or purely vertical landings as well as short or purely vertical takeoffs. These maneuvers may require skills not developed in previous aircraft the pilot has flown. They may also require the pilot to interpret external stimuli, either motion or visual, that he has never experienced before. Even the most capable high fidelity motion based flight simulators can not exactly duplicate actual flight conditions in the V/STOL regime for more than a few seconds.

A final characteristic of V/STOL flight, that is unique, is the increased hazard of operating a jet aircraft in the V/STOL environment. Due to close proximity to the ground and low speeds, there is little time for the pilot to save the aircraft or himself in the event of a problem. These unique aspects of V/STOL flight make it imperative to provide a student with the close instructor supervision and realistic flight conditions available only in a two-seat trainer aircraft.

CHAPTER I

HISTORICAL PRECEDENTS

General

In the last 40 years, many aircraft with vertical take-off and/or landing capability have been developed, but only two have seen successful operational employment. These two aircraft are the AV-8 Harrier, developed in the United Kingdom and the YAK-38 Forger, developed in the former Soviet Union. The Harrier is the only one of these two aircraft still in operational service today. Early testing of prototypes for each of these aircraft exposed not only the problems of designing an aircraft to operate in the (V/STOL) environment, but also identified hazards unique to that environment as well. The difficulty of operating these unique aircraft was recognized early, because development of two seat variants was considered in parallel to the single seat variants in both programs.

YAK-38/YAK-141

The former Soviet Union has developed several V/STOL type aircraft over the last few decades. The Yak-38 Forger was developed in the early 1970s. It utilized a lift plus lift/cruise engine configuration. The Forger was the only V/STOL aircraft developed by the former Soviet Union that saw operational service. Development of a two-seat trainer began almost immediately after the first prototype aircraft flew its maiden flight in 1971. Designated the Yak-38U, the two seat aircraft was deemed

essential due to the unique operating and handling characteristics of the aircraft. The first two-seat Yak-38 flew its maiden flight in 1973. Modifications to the basic airframe to include the second crew station increased the overall length by seven feet and the empty gross weight by 2000 pounds. In order to maintain some semblance of V/STOL capability, the radar and wing hardpoints were removed to offset the additional aircraft weight. In all, 38 Yak-38Us were built in a total aircraft production of 231 airplanes¹. Despite the fact that a two-seat variant was developed and utilized, it has been reported that 73% of all YAK-38 accidents occurred in the V/STOL regime.²

The follow-on aircraft to the YAK-38 was to be the YAK-141. Only two prototypes of the YAK-141 were built before the program was canceled. Although the program was canceled before prototype testing was complete, development of a two-seat variant had already begun. The YAK-141 employed a lift plus cruise propulsion system configuration and a Digital Flight Control System (DFCS). The YAK-141 began Vertical Take-Off and Landing (VTOL) flight testing in December 1989 and continued through October 1991 when one of the prototypes was badly damaged during a vertical landing. One causal factor of this crash was the pilot's lack of experience with the aircraft. Despite the lessons learned from the YAK-38 program and the advances in design, a two-seat variant was still considered essential to the YAK-141 program.

Harrier

The Harrier is the only V/STOL aircraft still in operational service today. The first version of an airplane that would eventually become the Harrier was developed in the United Kingdom in 1960³. This aircraft, the P1127, utilized a single engine direct lift

system with a very rudimentary type of V/STOL flight control system. The first single seat aircraft entered service with the United Kingdom's Royal Air Force in 1969 and was followed 16 months later by the first two-seat variant. The two-seat variant was developed in parallel with the single seat version. The goal was to develop a two seat aircraft that closely matched the flying qualities of the single seat variant, so that it could be used as both a conversion and operational trainer.

The single seat AV-8A Harrier entered service in the United States in 1971. Due to budgetary problems, however, the two-seat variant did not enter service until 1976. Several of the American military pilots that were selected to fly the Harrier were sent to the United Kingdom for training. Prior to the arrival of a two-seat variant of the airplane in the United States, pilots training to fly the Harrier were given several hours of instruction in a helicopter. This was done to introduce them to the slow speed and hover flight environment. Of the 110 AV-8As that were purchased by the United States, 55 aircraft were lost in accidents in a period of eleven years⁴. The AV-8A experienced an accident rate of 39 per 100,000 flight hours between 1971 and 1982. This was reduced to 19.5 per 100,000 flight hours from 1983-1987 due to initiatives that focused on improvements to pilot selection and training. The AV-8B brought significant improvements to the aircraft in the areas of flying qualities, performance and combat capability. Despite these improvements the aircraft still had a cumulative accident rate of 14 per 100,000 hours in its first seven years and continues to exceed the accident rate of other aircraft with similar missions by a significant amount. Figure 1-1 shows a comparison of accident causal factors for the AV-8B. More than 25 percent of the

AV-8B Mishap Causes (Class A, B, and C)

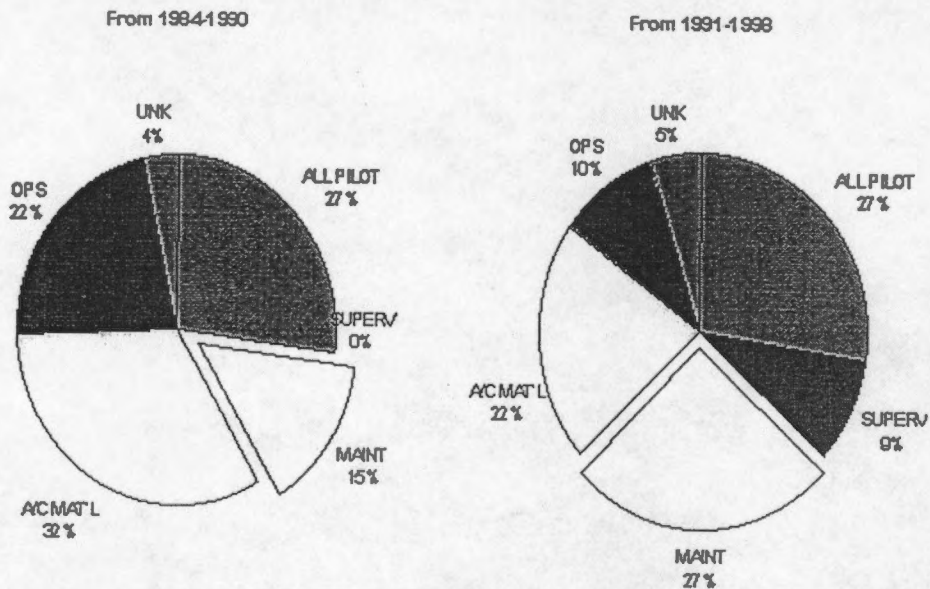


FIGURE 1-1 HARRIER ACCIDENT CAUSAL FACTORS

Source: *Harrier Action Review Panel (HARP) First Annual Report 1998*

accidents are attributable to pilot error which illustrates the difficulty of operating the aircraft and the hazards of the V/STOL environment.

Reducing Mishaps

Since their introduction, both the AV-8A and the AV-8B have had accident rates higher than most all other aircraft in the US military. In the past 20 years several studies have been conducted to help to understand and reduce the accident rate experienced by the Harrier. In all of these studies, flight training was a central issue. In 1991, an independent review of the Harrier program suggested two courses of action. The first

was that the aircraft be phased out. The second was that, if considered indispensable, significant changes to pilot selection and training management were required. It was the second option that was selected by the USMC and changes were implemented. Since that time, the emphasis on pilot training has been on operating the aircraft in the V/STOL environment. This includes the requirement to complete a high number of V/STOL type landings before completing the training syllabus. Along with these changes to the training syllabus, a policy was implemented that mandated a minimum score from initial jet training for selection to the Harrier training program

TABLE 1-1 SELECTED AIRCRAFT MISHAP RATES*

	USMC AV-8B	USMC F/A-18	USMC AH-1	USAF F-16	USAF A-10
1991	10.98	3.38	11.21	4.55	0.88
1992	12.50	2.32	3.40	4.04	1.79
1993	7.35	2.07	10.82	4.15	1.74
1994	7.98	0.96	0.00	4.00	3.35
1995	9.99	2.73	2.80	2.33	1.69
1996	10.16	4.12	2.56	2.14	1.63
1997	10.47	2.95	5.97	3.05	2.40
1998	12.41	3.23	0.00	3.89	0.81

*Per 100,000 flight hours

As shown in Table 1-1, the year after these policies were put in place (1993), a reduction in the Harrier mishap rate from 12.5 % to 7.35 % occurred. The increased awareness over the importance of V/STOL flight training in the Harrier was certainly a factor in the reduction in mishaps. It is not easy to ascertain whether it is the aircraft or the environment that is the more difficult. Advances in technology should ensure that the

next V/STOL aircraft developed for the military will have improvements in flying qualities, capabilities, and ease of operation over the Harrier. However, these advances may not guarantee that teaching a pilot how to operate in the V/STOL environment can be accomplished without the benefit of a two seat aircraft. Regardless of advances in aircraft design, the hazards of the V/STOL environment will always be present.

F-22B Development

The F-22 is a single seat, twin engine supersonic fighter currently in development for the United States Air Force (USAF). It utilizes a DFCS and has a limited two-dimensional thrust vectoring capability. Originally, the program intended to develop a two-seat variant, the F-22B, that would be combat mission capable but could also be used as a trainer. Budget constraints have forced the program to find ways to reduce cost. A recent study has determined that a combination of high fidelity simulator training and remote instructor supervision from a separate aircraft will be a safe and effective method of training new F-22 pilots. The study found that conducting pilot training without a two-seat variant would require an increase in simulator sorties, a decrease in student flying sorties, and an increase in support sorties. A support sortie is defined as one where the instructor flies in a separate aircraft and follows the student throughout the maneuvers required during the sortie.

The elimination of the F-22B would produce a significant reduction in program costs. The study concluded that a substantial cost would be incurred in the research and development of two seat variants. In a program already being scrutinized for cost increases, the savings from dropping the development of the two-seat variant would be

very important. The study did not provide any estimates of additional costs that would result from increased simulator and support sortie requirements for pilot training.

Although immediate savings could be realized from eliminating development costs of the F-22B, it is unclear if any savings in long term costs of the program would be achieved.

Several factors support the position that the students could successfully be trained in the F-22 without a two seat aircraft. The students would be coming from either a different fighter aircraft or a jet trainer. In either case, although the systems and handling qualities of the F-22 may be very different from the student's previous experience, the basic procedures and for takeoff and landing tasks are relatively the same. The same basic skills developed in other conventional aircraft would apply to flying the F-22. Likewise, sensations felt during takeoff and landing in other jet aircraft would be similar to those experienced in the F-22.

Other Aircraft Examples

There have been a few aircraft that have been developed with no two-seat trainer available. The A-10 is one example of this and boasts a low accident rate. A more current example is the F-117 Stealth fighter, which has a similarly low accident rate. However, in the case of the latter only very experienced pilots from other fighter aircraft backgrounds were initially allowed to fly that aircraft. These are clearly two examples that would support the reasoning that two seat aircraft are not required for pilot training.

Before this can be accepted as a solution for all future aircraft, several questions must be answered. First, how different are those aircraft from the ones the pilot flew previously? Second, how unique are the tasks the pilot must perform in those aircraft?

Last, how hazardous is the environment those aircraft operate in? We must bear in mind that before flying either the A-10 or F-117 the pilot has been trained in a dedicated two seat jet trainer aircraft. They have been taught fundamental skills required to takeoff, land and safely operate an aircraft under close instructor supervision. Once they have successfully completed their initial pilot training, these pilots can move into a new aircraft that performs takeoff and landings in the same basic manner but perhaps at different airspeeds. Fundamental operations of the flight controls remains very similar to the aircraft they were previously trained in, and the challenge becomes mastering the new aircraft and its systems. If a new aircraft operates using the same basic procedures and skills developed in previous aircraft, it is reasonable to assume that effective training could be accomplished without the use of a two seat aircraft.

CHAPTER II

UNIQUE ASPECTS OF V/STOL FLIGHT

General

There are several aspects of V/STOL flight that set it apart from conventional flight. These differences can be seen not only in the design of the aircraft but in the way in which it operates. The ability to land and takeoff at very slow airspeeds, including zero, allow the aircraft to operate from a variety of locations that a conventional aircraft cannot. This capability exposes the aircraft to the hazards of operating in close proximity to the ground. The unique aspects of V/STOL flight make the use of a two-seat trainer imperative

Flight Controls

One of the most notable differences between V/STOL and Conventional Take-Off and Landing (CTOL) aircraft is in the area of flight controls. Due to the speeds at which they fly, CTOL aircraft rely largely on aerodynamic surfaces to generate lift and for maneuvering the aircraft. As a V/STOL aircraft decelerates, aerodynamic lift decreases and propulsive lift increases. At some speed, the propulsion system provides all the lift required to keep the aircraft airborne. To maneuver, V/STOL aircraft must utilize other systems once aerodynamic surfaces are no longer effective.

One example of how this is accomplished is the Reaction Control System (RCS) in the AV-8B Harrier (see Figure A-1 in Appendix A). The RCS utilizes engine bleed air

to vent high velocity air at the wing tips, in the nose, and in the tail of the aircraft. The pilot operates the RCS by using the conventional flight controls. For example, a left stick command by the pilot opens the right wing RCS duct pushing the right wing up. With the aircraft banking left, the thrust from the exhaust nozzles now helps to push the aircraft to the left. Although the conventional cockpit controls are utilized, the aircraft response to control inputs is different. The RCS provides an acceleration response to control inputs while the conventional aerodynamic surfaces provide a velocity or rate change response to control inputs. During the deceleration, the throttle changes from controlling longitudinal accelerations or deceleration at higher speeds, to controlling vertical velocity in the hover. These examples clearly illustrate the change in control functionality the pilot experiences when making the transition from conventional to V/STOL flight. Flight control functionality changes are something that a pilot must master, to safely and effectively operate a V/STOL aircraft.

V/STOL aircraft also typically have controls that are used only in V/STOL flight. One example of this is the Harrier nozzle lever, which controls the angle of the thrust vector. Figure 2-1 is an AV-8B throttle quadrant which shows the separate throttle and nozzle controllers. Some V/STOL research aircraft have utilized thumbwheels on the throttle to control thrust vector angle. This eliminates the need for the pilot to move his left hand between two separate control levers during critical phases of V/STOL flight.

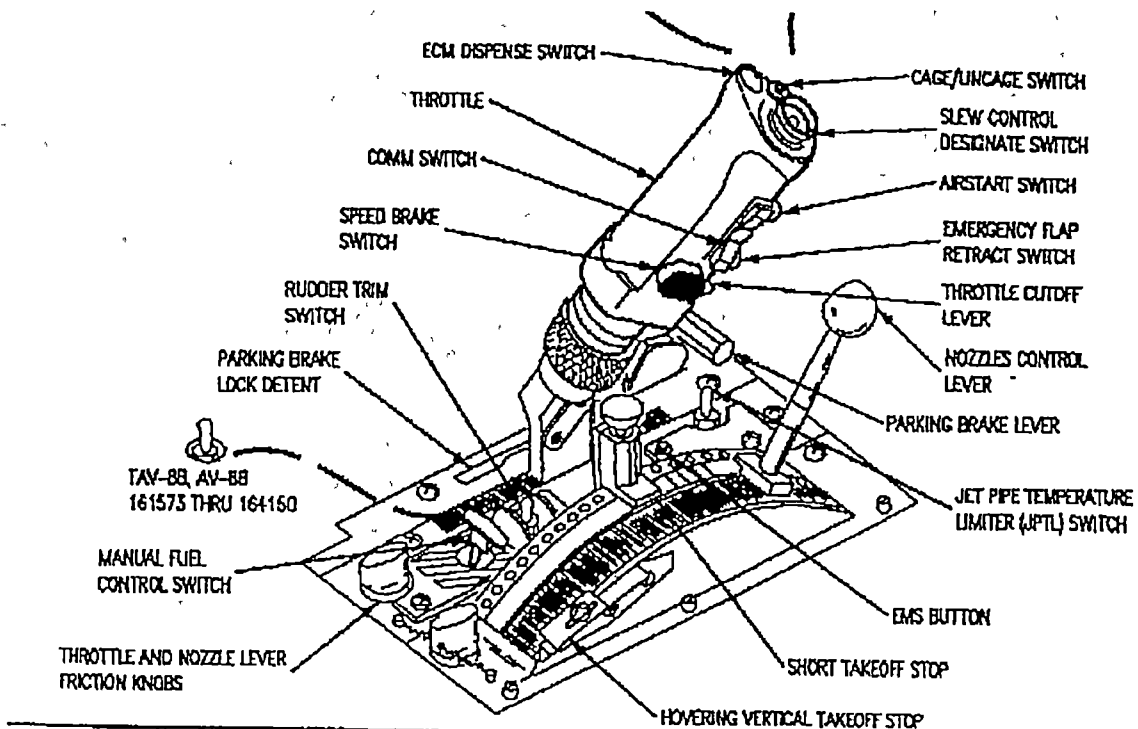


FIGURE 2-1 AV-8B THROTTLE QUADRANT ASSEMBLY

Source: *NATOPS FLIGHT MANUAL NAVY MODEL AV-8B* August 1995

In most cases, for a V/STOL aircraft, the engine becomes an integral part of the flight control scheme. In fact, current V/STOL aircraft are being developed with what is referred to as an Integrated Propulsion and Flight Control (IFPC) system. This describes not only the lift system but the cockpit controls or inceptors as well. Depending on the type of lift system configuration, these cockpit inceptors may vary. A pilot must learn how to effectively operate these inceptors to perform V/STOL tasks. The more inceptors the pilot has to manipulate simultaneously, the more difficult it is to fly the aircraft. Research into Advanced STOVL (ASTOVL) flight controls has shown that pilot

workload can be greatly reduced by reducing the number of inceptors the pilot must manipulate in V/STOL flight.

Aircraft Weight

A conventional aircraft usually has some restrictions on maximum landing weight. These may prohibit the aircraft from landing or require the pilot to utilize a lower than normal sink rate during landing. For most fighter aircraft, this weight usually exceeds the fully fueled weight of the aircraft. This means that a conventional pilot is only infrequently concerned with weight of the aircraft during landing. A V/STOL aircraft's ability to conduct a vertical landing is dependent on the relationship of vertical thrust available to the weight of the aircraft. In the case of an AV-8B the aircraft in most environmental conditions must be below half fuel weight before the aircraft has the performance to hover

V/STOL Flight Tasks

Military V/STOL aircraft are required to operate from a variety of shore based austere locations. These include roads, expeditionary airfields, and staging areas, which may be nothing more than 100 ft X 100 ft steel surfaces. Additionally, V/STOL aircraft are required to operate from ships at sea. Conventional shipboard aircraft utilize a tailhook that catches an arresting cable as the aircraft touches down on the deck of the ship at normal landing speeds. A V/STOL aircraft decelerates to a hover abeam the ship, translates across to the deck and performs a vertical landing. For takeoff, conventional aircraft utilize steam driven catapults to launch the aircraft off the ship. A V/STOL

aircraft executes a short takeoff under its own power to launch off the deck. Shipboard operations add the additional complexity to the landing task of a moving deck. The ship will roll, pitch and heave depending on the conditions of the sea. The V/STOL pilot must attempt to minimize the difference between aircraft attitude and ship attitude at touchdown. Prior shipboard experience with tailhook aircraft and arrested landings do little to prepare a pilot for shipboard V/STOL operations.

V/STOL aircraft often have to operate as conventional aircraft, requiring that the pilot be trained in these skills as well. However, to maximize the benefits of a V/STOL airplane the pilot is required to master additional skills. Specifically these include being able to safely and effectively operate the aircraft in the slow speed and hovering flight regime. A brief discussion of key points in the V/STOL flight regime follows.

Conversion

Initially the pilot must convert the aircraft from CTOL mode to V/STOL mode. This transition activates the lift system and enables the transition from wingborn to jetborne flight. If properly designed this conversion should be transition free. This means the pilot should not be required to make any control inputs to correct for uncommanded aircraft motion. During this conversion the aircraft may switch to a different set of flight control laws specifically used for V/STOL mode flight. This may result in a change in control effect and feel as well as cockpit displays. This is not uncommon in current fighter aircraft to switch control laws between the Takeoff/Landing

configuration and up and away configuration. This suggests a pilot may have been exposed to this transition before.

Approach and Landing

During an approach, the pilot is usually required to manage flight path, Angle of Attack (AoA), airspeed and lineup. Unlike conventional aircraft, which will decelerate to a predetermined airspeed or an optimum AoA, V/STOL aircraft can continue this deceleration to zero airspeed and hover. At some point in this deceleration the functionality of the flight controls may change, forcing the pilot to modify his control strategy. For example, in the Vectored-thrust Advanced Airborne Control (VAAC) aircraft research program, as the aircraft decelerated from 100 knots to 50 knots the right hand inceptor, which had been controlling pitch rate during the approach, changed to controlling height in the hover. The skills required to adjust to changes in functionality of the flight controls during an approach to landing have not been developed in other aircraft. The new V/STOL pilot must learn and develop these skills in order to operate safely and effectively in the V/STOL environment.

Establishing the hover requires arresting the forward speed and capturing a desired hover attitude and height above ground. In the AV-8B, the pilot must mentally judge his rate of deceleration controlling it so that he arrives at zero airspeed over his intended point of landing. Misjudging this deceleration could lead to overshooting the desired spot and being forced to go around for a second attempt or backing up which is difficult due to limited rearward visibility. The pilot could also undershoot the desired

spot forcing him to re-establish a closure rate and delaying the landing, which consumes more fuel.

Once established in the hover, the pilot sets a rate of descent, maintains position in both the x and y axis over the intended point of landing, and lands the aircraft. Touching down with no drift and in the proper touchdown attitude is essential to avoid structural damage to the landing gear. At some point in the descent the aircraft will be subject to ground effects, which will be discussed later, and experience a noticeable change in handling qualities. Table 2-1 shows a comparison of individual task elements required during landing for a Harrier, conventional aircraft, and an Advanced Short Take-Off and Vertical Landing (ASTOVL) aircraft. The ASTOVL aircraft listed is based on one flight control configuration being studied in the VAAC research program. The task elements for the conventional fighter are taken from the F/A-18 flight manual. Graphical depiction for the conventional landing as well as the Harrier landing can be found in Figures A-2 through A-4.

Take-Off

The pilot faces unique challenges during takeoff as well. Although a V/STOL aircraft may have the capability to takeoff conventionally, without the aid of the lift system, it may be desirable or necessary to execute a short takeoff or vertical takeoff in some scenarios

TABLE 2-1 TASK COMPARISON FOR LANDING

	Harrier	Conventional Fighter	AV/STOL Aircraft
1	Slow below 250	Slow below 250	Slow below speed
2	Lower gear and flaps	Lower gear and flaps	Configure to V/STOL mode
3	Arm thrust augmentation switch	Maintain 10-12° AoA with stick and throttle	Set deceleration rate via the accel/decel controller
4	Set nozzles 40 -60 degrees	Adjust flight path with throttle	Control flight path with throttle inputs initially
5	Maintain 10-12 deg AoA with stick and throttle	Maintain attitude and thrust setting to touchdown	As speed decreases, control attitude with right inceptor and height rate with left inceptor
6	Monitor decel rate	At touchdown throttle to idle	Monitor decel rate to arrive in hover at 100 ft over desired spot
7	At appropriate position nozzles to hover stop	Track down centerline using rudder pedals	Initiate descent with left inceptor reduction
8	Maintain pitch attitude	Below 100 knots apply brakes	Maintain position over spot with right inceptor
9	Adjust power to manage altitude		At touchdown left hand idle
10	Select ground references		Brakes full
11	Flare slightly to stop in hover		Set thrust vector aft
12	Initiate descent with throttle reduction		
13	Maintain position over spot with stick		
14	At touchdown reduce throttle to idle		
15	Brakes apply		
16	Nozzles aft		

Unlike a conventional aircraft that rolls down the runway until reaching a speed where the wings produce sufficient lift for takeoff, a V/STOL aircraft may takeoff at much slower speeds by using the propulsion system to lift the aircraft. The V/STOL aircraft can employ its lift system to execute a purely vertical takeoff from zero forward airspeed. Once the takeoff is complete, the pilot must fly the aircraft through a transition, this time from jetborne flight through semi-jetborne flight to conventional flight. In the Harrier, the pilot initially controls height rate with the throttle (left hand) and pitch attitude with the control stick (right hand). As the aircraft accelerates, the throttle controls longitudinal acceleration and the stick controls pitch rate. During this change in control functionality, the pilot must use his left hand to adjust the nozzle lever and rotate the nozzles, or thrust vector, aft. Further complicating the task is the requirement to raise the gear and flaps during this transition. At this point, the aircraft is flying in a purely conventional mode. Table 2-2 shows a comparison of individual task elements for a take-off for a current V/STOL aircraft, a conventional aircraft, and an ASTOVL aircraft. Once again it is clear that the number of task elements differ significantly, which illustrates the complexity of V/STOL operations.

Visual Cues

Vision is the most important sensory system that provides the pilot spatial orientation cues during flight. In the absence of vision, orientation would be derived solely from the less accurate vestibular or somatosensory systems. These systems do not provide reliable motion and position cues in the conventional flight environment⁵

TABLE 2-2 TASK COMPARISON FOR TAKEOFF

	Harrier	Conventional Fighter	VAAC Aircraft
1	Determine takeoff parameters	Determine takeoff parameters	Determine takeoff parameters
2	Set STO stop	Check flight controls	Complete checks
3	Advance power and check accel time	Advance power to full	Configure to V/STOL
4	Lower nozzles check duct pressure flap position	Release brakes	Set STO nozzle angle
5	Set nozzles to 10°	Track centerline	Set thrust vector aft
6	Advance throttle to full	Rotate at predetermined speed	Advance power
7	Release brakes	Set fly away attitude	Release brakes
8	Track centerline	Raise gear and flaps	Track centerline
9	At STO Speed quickly move nozzles to 60°		Press STO button
10	Capture fly away pitch attitude		Maintain fly away attitude
11	Slowly nozzle out		Nozzle out
12	Raise gear and flaps prior to 250		Raise gear
13	Control flight path with nozzle rate and throttle		

Visual cues are particularly important during the approach and landing phase, especially during V/STOL operations.

During the decelerating transition the pilot is relying on both forward and peripheral vision to determine closure rate on the desired hover spot. As the intended point of hover approaches, the pilot selects ground references that will place the aircraft over the desired landing spot. Ideally, these ground references are at a 45 degree angle from the nose of the aircraft so the pilot can judge both forward and lateral aircraft motion from a single reference point. Once beginning the descent to landing, the pilot can see the landing area markings and make position refinements prior to touchdown. The pilot's field of view in the cockpit is limited by the structure of the aircraft. In the AV-8B, the canopy is slightly bubbled out to affording the pilot better visibility of the landing area in a vertical landing. The pilot can easily choose different ground references as required based on the environment. In the hover, the best indication of small drift rates is based on visual feedback. Field of view limitations, in any future V/STOL aircraft, will greatly impact the techniques utilized to control position during vertical operations.

Motion Cues

Buried in many body structures, including the skin, joints, and muscles, are somatosensory sensors. These sensors provide important equilibrium information as they respond to pressure and stretch. The sensations they elicit are the pressing feelings that you experience when you sit or the sensations that enable you to know the relative positions of your arms, legs, and body. This system is commonly called the "seat-of-the-

pants" sense. Early aviators believed they could determine which way was down by analyzing which portions of their bodies were subject to the greatest amount of pressure. In several phases of flight these sensations can be misleading. However, in the slow speed and hover environment they are more reliable. The pilot is capable of feeling accelerations in all six axes (Roll, Pitch, Yaw, Longitudinal, Lateral, and Vertical). In the V/STOL flight regime, sensing accelerations in the vertical axis can be crucial. While the pilot's scan is diverted from his altitude references, sensing slight accelerations on the body continues to provide information on the aircraft's movement. The motions associated with hovering flight are very difficult to simulate and are only truly experienced in an actual aircraft.

Winds

A conventional airplane can be affected by winds on landing forcing the pilot to slightly modify his landing technique. The effects of winds can usually be countered by aerodynamic flight controls at landing speeds of conventional airplanes. In slow speed or hovering flight the pilot can no longer rely on aerodynamic controls and must now utilize the IFPC to control aircraft direction. In the Harrier, transitioning from conventional flight to hovering flight takes the aircraft from a region of relative stability through a region of decreased stability. The pilot must strive to keep the nose of the aircraft pointed into the wind. The effects of crosswinds can be minimized through use of a DFCS. V/STOL aircraft can rely on fountain effect for lift. The fountain effect is the result of the jet exhaust hitting the ground underneath the aircraft and bouncing back up, hitting the underside of the aircraft. This helps to lift the aircraft a small amount. Strong

winds can blow the fountain out from underneath the aircraft and cause a loss of overall lift

Jet Effects

Several factors affect how a V/STOL aircraft behaves in close proximity to the ground. One is the effect from the jet exhaust leaving the airplane and hitting the ground and bouncing back up to hit the underside of the aircraft. This reflected flow could impinge the underside of the aircraft at any location, depending on aircraft attitude. These effects are illustrated in Figures A-5 and A-6. This impingement can be a strong destabilizing effect in the hover, which can negatively impact the handling qualities of the aircraft. Depending on the type of flight controls utilized in the design, there may be insufficient control authority available to counter an excessive build up of acceleration in any given axis. Another jet induced effect, is that the air entrained by the high-speed flow of the exhaust can cause a suck down effect, accelerating the aircraft downward.

A third effect is Hot Gas Ingestion (HGI). This is simply when the hot gases from the engine exhaust enter the engine intake. This effect raises the engine operating temperature and can reduce engine performance. This loss of thrust can tend to accelerate the aircraft downward. Finally, the strength of the exhaust hitting the ground may dislodge debris. This debris can impinge the aircraft causing structural damage or even more serious, enter the engine through the intake and cause engine failure. Figure A-7 shows reingestion developing as the aircraft slows in forward speed.

Operating Environment

The ability to either recover an aircraft or escape from it, in the event of an emergency, is based on several factors. One of the most important is height above the ground. Generally speaking, the higher the aircraft is above the ground the more time exists before it can impact the ground. Airspeed is often considered an important factor as well, but its benefit is to provide the pilot with the ability to climb away from the ground. In the V/STOL environment, the aircraft is at slow or zero airspeed and relatively close to the ground. This means there is very little time for a pilot to react to an aircraft problem before ground impact. Similarly, the time for escape from the aircraft is reduced. Figure A-8 shows the ejection envelope for an AV-8B in a hover. Due to close proximity to the ground, there is a point where the aircraft's attitude or sink rate may preclude the possibility of a safe ejection. In a two-seat trainer, the experienced instructor pilot may recognize a dangerous situation well before the student. The instructor could take quickly intervene in this scenario and take over the flight controls.

CHAPTER III

FLIGHT TRAINING METHODOLOGY

Building Block Approach

The majority of military flight training follows a building block approach; each task you perform builds on one you have previously completed. V/STOL flight training is no exception. Classroom instruction is followed by simulator training, which is followed by flight training in a two seat aircraft. All of this occurs before a student is allowed to fly on their first solo mission.

Throughout the course of training, the student is constantly repeating a three step process. The first step is having a task introduced by an instructor in a two seat aircraft or simulator. The second step is for the student to practice the technique. The final step is for the student to perform the task to a satisfactory level, based on established criteria. This process attempts to ensure that the student has sufficiently mastered one task before being allowed to proceed on to the next task or phase of flight. During the practice portion of this process, feedback from an instructor on the student's technique is critical. This timely feedback allows the student to correct any deficiencies. Without a two seat aircraft the opportunity for an instructor to demonstrate proper technique for a specific task does not exist. Additionally, the ability of an instructor to provide real time feedback on student technique is limited. If there is no two-seat aircraft available, the instructor will usually monitor the student from a remote location. From this external observation position, the instructor can only evaluate what the aircraft does and must rely

on experience and judgment to assess what the student pilot was doing with the controls. In the event of an emergency the instructor can only offer voice commands to help the student.

In order to accurately ascertain the requirements for V/STOL flight training, we must look at how it compares to conventional flight training. From the early stages of flight training, a student is taught the basic techniques of landing an aircraft. These include controlling flight path, AoA, and lineup with the runway. As the student progresses he develops the skills to handle crosswinds and off nominal type landings. As aircraft become more sophisticated, the basic techniques of landing remains relatively unchanged from the early days of jet flight training. As an example, U.S. Navy training teaches the student how to utilize the Optical Landing System (OLS) as a visual reference to land the aircraft at a precise spot. The student is exposed to various mission skills and systems as they progress through flight training but the basic ship type landing is always used. Because of this, it is reasonable to assume that a student could land a brand new aircraft, without the aid of an instructor, utilizing previously learned techniques. In this situation evaluating and monitoring the student from a remote location may be sufficient to assist in refinement of his skills. Systems and procedures specific to the new aircraft could be taught in a flight simulator.

V/STOL Flight Training

V/STOL flight training follows the same building block approach. Prior to being assigned to Harrier training in the USMC, a student has completed flight instruction in

turbo-prop and jet aircraft. At this point the student has acquired 200-300 total hours of flight time and has been taught basic aircraft skills. About one third of his flights have been solo, and he has basically learned one type of takeoff and landing. Initial V/STOL flight training uses two seat aircraft as an integral part of the training syllabus.

If there is no two-seat V/STOL trainer available, the student will be performing unique V/STOL tasks for the first time in an aircraft by himself. His previous experience in conventional aircraft is of little help in this situation. Fundamental changes in the flight control laws may occur as the aircraft decelerates, which most likely is also a new experience for the pilot. Additionally, unless the flight simulator used in V/STOL training had very realistic visual, motion, and audio capability, the student may be experience sensations that are completely new as well.

Current AV-8B Training Syllabus

The first step in determining future training requirements for pilots is to analyze current V/STOL training methodology. The current AV-8B training syllabus is presented in Table 3-1. Naturally, the training system that has been developed over the course of the past 20 years is directly related to the level of difficulty of flying the AV-8B. Over 59% of the current training syllabus for the AV-8B is dedicated to the V/STOL environment. Only a few categories listed above are dedicated to flight in the V/STOL environment. These are Familiarization, Field Carrier Landing Practice, and Forward Based Operations. The table does not reflect that on most all the other types of listed sorties, V/STOL flight techniques are practiced during some portion of the flight

TABLE 3-1 CURRENT HARRIER TRAINING SYLLABUS BREAKDOWN⁶

Flight Phase	Number of flights required		
	Single Seat AV-8B Flight	Two Seat TAV-8B Flight	Simulator
Familiarization (Day)	4	11	13
Familiarization (Night)	1	2	1
Instrument	0	2	4
Formation (Day/Night)	2	2	N/A
Navigation	0	2	3
Aerial Refueling	1	N/A	N/A
Air to Ground	6	4	8
Low Altitude Tactics	0	1	0
Air Combat	4	0	1
Forward Based Operations	8	2	2
Field Carrier Landing Practice	6	0	2
Combat Capable Check Ride	0	1	2
Total	31	27	36

Prior to completing training, an AV-8B student has to complete 100 Vertical Landings (VL) and Rolling Vertical Landings (RVL). The emphasis on a high number of V/STOL landings was initiated in 1992 after the meeting of a Harrier Safety Review panel. For comparison students training for a conventional aircraft, like an F/A-18, spend the majority of training time learning basic aircraft skills and basic combat skills. An F/A-18 student also completes day and night Carrier Qualification as part of the training syllabus. An AV-8B pilot completes only shore based practice portion of Carrier Qualification, and never actually lands aboard a ship. Both the F/A-18 and AV-8B syllabi have a similar number of total sorties, but the AV-8B student spends the majority

of his training learning how to operate in the V/STOL environment. His combat skills are left to the frontline squadron to develop. Again, some may claim that the amount of training dedicated to V/STOL flight is directly related to the difficulty of flying the airplane. If true, it would be necessary to ensure that a future V/STOL aircraft is easier to fly than the AV-8B in order to begin to reduce V/STOL training requirements from their current levels. Another reason for the amount of training required is the unique aspects of the V/STOL environment. Regardless of future aircraft design, these environmental aspects will always be present.

Conversion/Refresher Training

Not all pilots who begin V/STOL flight training are initial trainees with little previous experience. Two other categories of pilots requiring training also exist. The first is refresher pilots or those with V/STOL backgrounds who haven't flown in over a year⁷. Refresher pilots undergo an abbreviated syllabus but use of a two-seat trainer is still required. The syllabus for an AV-8B refresher pilot is shown in Table 3-2. The second is conversion pilots or those with backgrounds in other aircraft. A pilot converting from another type of aircraft may have habit patterns, which, although successful for operating their previous aircraft, may be hazardous when applied to a V/STOL jet aircraft. An example of this would be a pilot of a rotary wing aircraft, whose habit pattern to execute a vertical climb is to pull an inceptor with his left hand. In a V/STOL jet aircraft however the same maneuver may require pushing an inceptor with the left hand. Currently in the AV-8B conversion pilots undergo a training syllabus almost identical to that of a new pilot. Although they may have significant experience in

TABLE 3-2 HARRIER REFRESHER SYLLABUS⁸

Flight Phase	Number of flights required		
	Single Seat AV-8B Flight	Two Seat TAV-8B Flight	Simulator
Familiarization	1	2	9
Instrument	2	0	0
Formation (Day/Night)	1	0	N/A
Navigation	1	0	1
Air to Ground	1	0	7
Check Ride	0	1	1
Total	6	3	18

another aircraft, they lack those skills necessary to perform those unique V/STOL tasks. Even pilots, who have previously been qualified in the AV-8B and have not flown the aircraft in over 18 months, spend 40% of their refresher syllabus with V/STOL training

Two Seat Aircraft

As previously stated several aircraft have been developed with two seat variants that have been utilized as flight trainers. The front cockpit usually is a close match to the single seat version of the airplane, while the aft cockpit may have only the items essential to basic operation of the aircraft. This setup allows the instructor the ability to demonstrate maneuvers, intervene, and, if required, override the student's control inputs while performing a maneuver. Being co-located in the same aircraft the instructor is experiencing the same noises, sights, and motion as the student. This allows the instructor to provide immediate relevant feedback to the student before during and after maneuvers

The instructor also has the capability to either correct a hazardous situation or eject the crew if the aircraft cannot be recovered.

The TAV-8B is an example of a two-seat trainer designed to closely match the flying qualities of the single seat version for use as a student trainer. Although it has some limitations as far as performing combat missions the single seat version can perform, in the V/STOL flight regime the two aircraft are virtually identical. The basic V/STOL handling qualities are the same, as well as the procedures and techniques required for V/STOL tasks. A student can develop the necessary skills required for V/STOL flight in the two seat aircraft under close instructor supervision, and directly transfer those skills to the single seat aircraft. The AV-8B simulator does not offer the same direct transfer of skill for V/STOL tasks to the single seat aircraft that the TAV-8B offers.

The current training syllabus for the AV-8B shows a heavy reliance on the two-seat trainer in the initial stages of training. Currently twelve two-seat aircraft support the training requirements for the Harrier program in the USMC. All operational V/STOL aircraft so far have used two seat variants as trainers. This has been based largely on the difficulty of operating these aircraft in this relatively new flight regime. Therefore, even if future V/STOL aircraft are made easier and safer to fly there will still be the issue of training a student in a flight regime they have not operated in previously. A two seat V/STOL aircraft is the best solution to accomplish this training.

CHAPTER IV

FLIGHT SIMULATORS

General

Recent advances in computer technology have greatly improved the degree of realism available in flight simulators. These simulators provide a safe environment in which to train difficult maneuvers since there is no risk to pilot or aircraft. This safe training environment, and relatively low operating costs, has led to a greater reliance on flight simulators for pilot training. In order to train pilots to fly these sophisticated aircraft, several options are being analyzed. The current trend in pilot training requirements is towards greater reliance on high fidelity flight simulators in lieu of actual aircraft training sorties. Advances in computer technology have enabled more realistic visual displays and more representative aircraft motion simulation in the majority of flight conditions. Despite these advances, there are still limitations in the degree of realism flight simulators can provide for certain tasks and in certain flight regimes. These limitations include, among other things, accurately representing the V/STOL environment.

Piloted simulation has served a variety of uses since its inception. These include.

- a) Normal Procedures Training
- b) Emergency Procedures Training,
- c) Basic Flight Training,
- d) System Specific Training,

- e) Weapons Training,
- f) Full Mission Rehearsal Training and,
- g) Multi-aircraft Training.

There are several types of simulators utilized in pilot training. The degree of realism that the device can simulate is often referred to as fidelity. Low fidelity simulators, such as Part Task Trainers, are used to teach specific system operation or basic procedures. These simulators may consist of nothing more than crude cockpit mockups with some functioning switches and buttons. Fixed Based Simulators can provide visual displays and attempt to match aircraft capabilities. Motion Based Simulators can provide accelerations to the pilot station to simulate aircraft motion. In these higher fidelity devices, the pilot can simulate virtually all aspects of the aircraft's capability as well as a broad spectrum of aircraft missions. This analysis will focus on those simulators at the higher end of the fidelity spectrum, since they are the most likely to be used for teaching a student how to fly.

In order to be effective a simulator must accurately represent the aircraft and the environment in which it operates. The more closely the simulator matches the real aircraft the more beneficial the training it provides. Items such as the cockpit environment, control feel, and aircraft performance are some areas of interest. The cockpit environment covers proper configuration and operation of controls and displays, as well as accurate representation of noise, vibration, and other sensory clues. The device must accurately represent the aircraft not only in flight, but on the ground as well. Realistic representation of aircraft performance includes things such as proper response

to flight control inputs, accurate aerodynamic behavior, and accurate engine modeling

Figure 4-1 shows a summary of items that affect how a pilot performs a task in the aircraft.

As computer technology and graphical display capabilities have advanced, greater degrees of realism have been achieved in flight simulators. With this increase in realism, there have been efforts to replace more expensive aircraft flights with less expensive simulator events. This approach has several advantages such as lower cost, safety, and more combat realistic scenarios. There is a disadvantage to this approach if the simulator is not truly representative of the aircraft. In this case, the proper skills to fly the aircraft may not be developed.

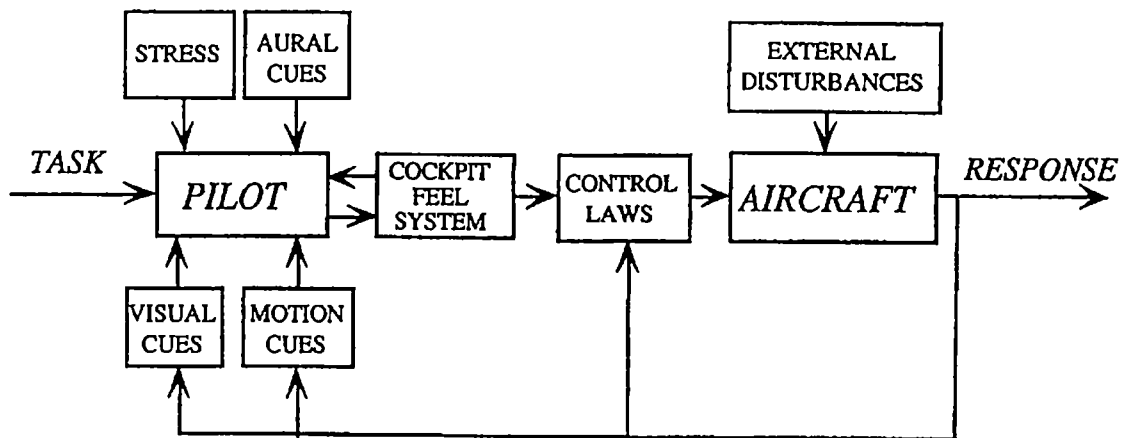


FIGURE 4-1 PILOT FEEDBACK AND AIRCRAFT RESPONSE

Source. *Augmented Aircraft Handling Qualities*, Knotts, L. & Ohmit, E Sep 1994

Visual Systems

There are several different types of visual systems utilized in flight simulators today. Computer Image Generators (CIG) are used to produce graphical representations of terrain, other aircraft, buildings, etc. that are projected onto some type of screen arrangement that can be viewed by the pilot. These displays can be single panel, multi-panel, or full size domes that encompass the crewstation. The most common consists of three flat panel displays providing the pilot a predominantly forward field of view. Different weather conditions and lighting conditions, from bright day to dark night, are usually available. The visual databases will typically contain a wide array of images that can support a variety of mission tasks.

The degree of realism that can be produced in the visual scene depends on several factors. One of these is the speed and capacity of the Computer Image Generators. This affects how fast the visual scene can change from one frame to the next. Additionally, the delay in change of the visual scene in relation to flight control input is affected by the capability of the computers. Each of these parameters is critical in determining not only the level of realism, but the utility of the simulator for certain tasks. For example, if there is a significant delay between flight control input and change in the visual scene, the pilot may be induced to make exaggerated control inputs when there is no immediate response to initial inputs. During V/STOL training, this could be particularly detrimental for a shipboard VL conducted in inclement weather conditions. The magnitude and frequency of control inputs the pilot learns in the simulator may be dangerously excessive in the actual aircraft under similar conditions. If the simulator is the only training tool

available, this could expose the new pilot to risks on his first solo flight, especially in the V/STOL environment.

Field of View

Another important aspect of the visual display is field of view. As mentioned previously, full dome projection simulators are in use today. Unfortunately, as the projection area grows larger, the resolution of the image suffers. Most simulators in use today utilize a three-panel display that provides high resolution for a predominantly forward field of view. High resolution can be achieved in dome simulators but this is usually achieved by limiting the higher resolution display to a small area around the pilot's focal point. This is accomplished by a device that tracks the pilot's head movement. Outside of the area the pilot is looking directly at, a much lower resolution image is projected.

One of the requirements for V/STOL flight is the ability to use ground references for positioning the aircraft during a vertical landing. Some scenarios require that the pilot be able to position the center of the aircraft within a five-foot circle on the ground. In order to achieve this, the pilot needs some visual display below the horizon. Most simulators have very limited capability in this area. In aircraft such as the AV-8B, the canopy is bowed out in such a way that the pilot has almost 70 degrees of visibility below the horizon on either side of the cockpit. This is a tremendous aid in precisely positioning the aircraft during a vertical landing. If the field of view in the simulator is not the same as the aircraft, the pilot may not develop the proper frame of reference required to safely and effectively complete the task. An example of field of view data for

TABLE 4-1 SIMULATOR FIELD OF VIEWS

	Up (Degrees)	Down (Degrees)	Lateral (Degrees)
AV-8B Full Dome Tactical Trainer	70	45	110
AV-8B Operational Flight Trainer	20	50	120
NASA Vertical Motion Simulator	9	17	50
Lockheed Martin JSF Simulator	19	17	140

a variety of flight simulators currently in use is provided in Table 4-1. The numbers provided are referenced to the horizon for up and down, and the centered on the nose of the aircraft for lateral.

Motion Systems.

Another critical aspect that determines the fidelity and utility of a simulator is the ability to represent aircraft motion. Obviously matching the actual motion of an aircraft cannot be achieved by a ground based device confined to a room or building. Several methods of providing the sensation of actual aircraft motion are utilized in simulators today. The amount of motion can range from small changes in the pilot's seat, up to several degrees of change in roll, pitch, and yaw as well as limited displacement in the longitudinal, lateral, and vertical axes. As the range of motion increases the size, cost, and complexity of the simulator increases. By utilizing changes in acceleration and direction, these simulators can provide the pilot with very realistic feeling motion cues in several flight regimes

Examples of the motion capabilities of two simulators are shown in Tables 4-2 and 4-3. The NASA Vertical Motion Simulator (VMS), pictured in Figure A-9, is one of the most capable motion simulator available today. It is, however, a one of a kind device and is considered a national asset of the United States. The building that contains the VMS is over five stories tall. Due to its unique status and capabilities, the VMS is always in high demand by a variety of users. It would be impossible to attempt to access this device frequently enough to be effective as an initial V/STOL flight trainer. Likewise, the cost of the military constructing a similar device would be prohibitive. The Lockheed Martin simulator is more representative of the type of simulator that could be utilized for V/STOL flight training. It is approximately the same size as current military doomed simulators. The pilot station in this device sits on a set of hydraulic legs that allow movement in six degrees of freedom. It's size and cost would probably be reasonable for use as an initial V/STOL flight trainer. It should be noted that current AV-8B simulators utilize a "G-seat" as the only motion cueing to the pilot. This type of seat inflates and deflates to provide a very rudimentary simulation of aircraft motion. The current AV-8B Radar/Night Attack System Trainer (RNAWST) is shown in Figure A-10.

One of the limitations of the motion capability is the amount of displacement the device can achieve. Although the device may be able to generate realistic initial accelerations, it cannot sustain them for very long. At some point before hitting it's motion limits, the device will have to washout or dampen the velocity in that direction.

TABLE 4-2 NASA AMES VMS MOTION SYSTEM PERFORMANCE LIMITS⁹

Degree of freedom	Operational Limits		
	Displacement	Velocity	Acceleration
Longitudinal	± 3 ft	± 4 ft/sec	10 ft/sec ²
Lateral	± 15 ft	± 8 ft/sec	16 ft/sec ²
Vertical	± 22 ft	± 15 ft/sec	24 ft/sec ²
Roll	± 18 deg	± 40 deg/sec	115 deg/sec ²
Pitch	± 18 deg	± 40 deg/sec	115 deg/sec ²
Yaw	± 24 deg	± 46 deg/sec	115 deg/sec ²

TABLE 4-3 LOCKHEED MARTIN TACTICAL AIRCRAFT SIMULATOR MOTION SYSTEM PERFORMANCE LIMITS¹⁰

Degree of freedom	System Limits		
	Displacement	Velocity	Acceleration
Longitudinal	± 4 7ft	± 2.3 ft/sec	± 25.6 ft/sec ²
Lateral	± 4 0 ft	± 2 3 ft/sec	± 25.6 ft/sec ²
Vertical	± 5.7 ft	± 2 ft/sec	± 32.0 ft/sec ²
Roll	± 28.0 deg	± 24 deg/sec	± 250 deg/sec ²
Pitch	± 33.5 deg	± 24 deg/sec	± 250 deg/sec ²
Yaw	± 37 5 deg	± 24 deg/sec	± 250 deg/sec ²

Eventually the device will come to a stop when it reaches its motion limit. This may not correspond well with what the pilot is doing in the simulator at the time. This may produce a very unrealistic motion effect. Additionally, the simulator may not have representative motion limits in all axes. For example, the Lockheed Martin simulator listed above has only 37.5 degrees of motion available in yaw. This means if the pilot is trying to practice a 360 degrees turn while in a hover the motion would wash out very early in the maneuver.

The same concerns over the accuracy of the visual system are true for the motion system as well. Delays in response to control inputs or improper motion can be very detrimental to training. They can provide false cues to the pilot which lead to improper control inputs. In V/STOL flight, small changes in accelerations felt at the pilot station can provide additional awareness to the pilot of the aircraft's condition. In some cases, especially at night, these acceleration changes can provide earlier cueing to the pilot than what he can discern.

Accurate Modeling

The closer the simulator mimics the real aircraft characteristics, the more effective the training it can provide. This includes characteristics such as cockpit layout, feel of the flight controls, flying qualities and performance. Aircraft capabilities, derived from testing, are incorporated into the simulator. The more complex the aircraft, the more testing is required to develop an accurate simulator. Also, as the aircraft matures and changes, the simulator must change accordingly so that it may continue to be an effective training tool. Upgrades to the simulator may be costly and difficult to implement.

In order for a simulator to accurately match the capabilities of the aircraft, it must have accurate aerodynamic and engine models. This is essential so that when a pilot applies some control input, the simulator responds the same way that the aircraft would. This includes items like roll rates, engine accelerations, transonic effects, and gust response to name a few. The simulator must also have an accurate landing gear model so that it can simulate aircraft performance on the ground. An accurate landing gear model allows the pilot to use brakes and steering during taxi, takeoff and landing practice. For V/STOL flight, ground effects must be accurately modeled to provide realistic aircraft motion close to the ground.

The simulator must have an accurate engine model. This is essential for V/STOL flight because at some point the thrust from the engine directly affects movement of the aircraft in the vertical axis. If the simulator engine model is not accurate, the pilot may develop techniques, involving certain amounts of throttle change, that work well in the simulator but are either ineffective or dangerous in the aircraft.

Matching the flight control hardware in the simulator is fairly simple. Identical units to those used in the aircraft can be incorporated in the simulator cockpit. Matching the mechanical characteristics or "feel" of the flight controls is more complex. Several factors contribute to the problem of matching mechanical characteristics accurately. In the aircraft, motion and vibration can affect the pilot's input to the flight controls. For example, when the aircraft is subject to increased normal acceleration or "g" forces the weight of the control stick will increase. The force gradient of the control stick must be set to allow the pilot to continue to make desired control inputs in this condition. Current

flight training simulators cannot accurately duplicate these high g forces. This implies that the control stick force gradient in the simulator may not feel like the aircraft when performing the same type of maneuvers. Improper control feel in the simulator degrades the effectiveness of that simulator as a training tool.

To ensure the simulator has the desired level of fidelity in the required areas requires considerable aircraft testing. This testing and validation must continue through the life of the aircraft. As changes are made to the aircraft that affect its characteristics, these changes must be incorporated in the simulator to keep it effective as a training tool. The costs to develop, operate, and maintain these types of high fidelity simulators may not be significantly different than the costs of a two seat aircraft.

Comparisons to the actual aircraft, across the entire flight envelope, must be made. Delays in response, in either the visual or the motion system, must be virtually identical to those that exist in the aircraft. Figure 4-2 shows some of the sources of delays and factors that influence a pilot performing a task. If the simulator cannot accurately match all of the items shown, the training effectiveness of the device is degraded.

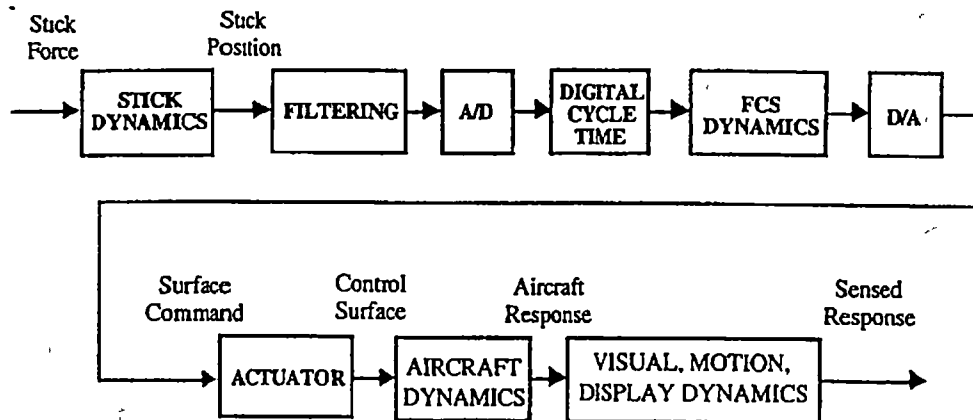


FIGURE 4-2 SOURCES OF DELAY IN AIRCRAFT SYSTEMS

Source *Augmented Aircraft Handling Qualities*, Knotts, L. & Ohmit, E. Sep 1994

Degree of Realism

One last item to consider when considering flight simulators is how to duplicate the stress level the pilot feels in the actual aircraft. Several studies have been conducted which monitor a pilot while he performs the same tasks in flight and in a simulator. One measure of stress level that is frequently used is heart rate. Figure 4-3 shows a trace of heart rate for various phases of a typical mission in flight and in the simulator. The differences, especially for takeoff, between the actual aircraft and the simulator are apparent.

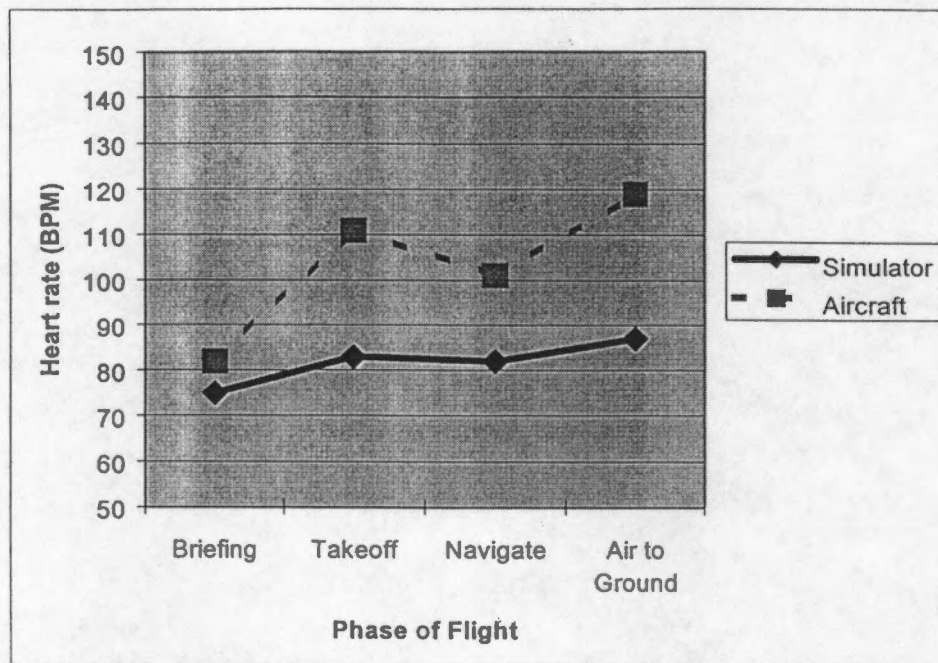


FIGURE 4-3 HEART RATE DURING MISSION TASKS

Source: *Piloted Simulation Effectiveness*, AGARD Conference Proceedings 513, Feb 1992

Part of this comes from the fact that the pilot knows he cannot be hurt in the simulator, but can be injured or killed in the actual aircraft. This suggests that a pilot may be tempted to use a techniques or procedures in the simulator that differ from the ones he would use in the real aircraft. For example, if the aircraft experienced an uncontrolled roll over in the hover, the pilot would most likely eject prior to reaching a bank angle that would preclude ejection. In the simulator, however, he may be tempted to try to recover the aircraft a bit longer since he knows that he cannot be injured if the simulator crashes. This is only one example of the differences in pilot behavior that may occur between the simulator and the aircraft. This is a critical problem if the simulator is

the primary training device due to the lack of a two-seat trainer. These differences highlight a shortcoming in the simulator's effectiveness as a training tool.

Simulator vs. Aircraft Comparison

A few studies have been conducted to directly compare simulator task performance between simulators and aircraft. Typically the results show that pilots will use control inputs of larger magnitude and frequency in the simulator as compared to the actual aircraft. This can be due to improper modeling in the simulator, lack of motion cues, or lack of visual cues. Table 4-4 shows a comparison of simulator results to actual aircraft results for a V-22 performing a shipboard landing. The V-22 is a tiltrotor V/STOL aircraft currently beginning initial operations with the USMC. Lateral stick inputs are close for the vertical landing but differ significantly during the approach phase. In each case, the average inputs are similar, but the range of inputs was larger in the simulator. Longitudinal stick inputs vary considerably for both approach and vertical landing.

This was identified as weight and balance modeling problems with the simulator. A large discrepancy also exists in the time required to complete the task. One reason was due to ground effects not actually being modeled in the simulator. These effects forced the pilot to stabilize in hover close to ground prior to landing. A secondary reason for the difference in time required to complete the task was pilot anticipated consequences of possible error. This further illustrates how differently pilots fly a simulator when they realize there is no risk of injury.

**TABLE 4-4 RESULTS OF SIMULATOR TO FLIGHT COMPARISON FOR V-22
SHIPBOARD EVALUATION¹¹**

Parameter	Simulation	Actual
Rate of Descent (feet per minute)	250-270	200-225
Task Time required for Approach (Seconds)	20-30	30-50
Task Time required for Vertical landing (Seconds)	5-8	12-20
Lateral Stick during Approach (% of maximum)	28-76	49-55
Lateral Stick during Approach (% of maximum)	38-63	39-59
Longitudinal Stick during Approach (% of maximum)	10-34	56-65
Longitudinal Stick during Vertical landing (% of maximum)	20-30	50-56
Bank Angle during Hover (deg)	3L to 4 R	2R to 3R

Simulator Effectiveness

One approach to trying to determine simulator effectiveness is to conduct transfer of training analysis. A common method used for this is Backwards Transfer Analysis. This is accomplished by selecting a group of pilots experienced in an aircraft. The pilots are asked to perform tasks in the aircraft and then they are graded on their performance. These pilots are then graded on their performance of the same tasks in the simulator. The grades are compared and the pilots are interviewed to provide comments on differences revealed.

One such study was conducted using a group of 15 attack helicopter pilots. The maneuvers performed were emergency landings with a variety of system failures. The

grades were uniformly lower in the simulator than in the actual helicopter. The pilots cited simulator limitations as the reason for the difference in grades. Table 4-5 lists some

TABLE 4-5 FACTORS CONTRIBUTING TO LOW BACKWARDS TRANSFER¹²

Simulator Deficiency	Percentage of pilots who agreed
Unable to judge altitude near ground	94
Insufficient visual cues to maintain hover	87
Lack of peripheral cues	69
Unrealistic response to cyclic input	75
Unrealistic response to collective input	69

of the simulator deficiencies responsible for the low backward transfer and the percentage of pilots who agreed with them.

The results of this study show a low transfer of skill from the aircraft to the simulator. It should be noted that the visual device used for this simulator was a camera and model board system. Several of the problems noted in this study were indicative of the type of visual system used. Most simulators today utilize computer graphic displays. This study does emphasize the importance of high fidelity in flight simulators in order for them to be effective training tools. But even the high fidelity may not be enough to rely on the simulator as the primary training tool in the absence of a two-seat trainer.

CHAPTER V

ADVANCES IN V/STOL TECHNOLOGY

Advanced V/STOL Flight Controls

Several research programs have been conducted to investigate various control and inceptor strategies for V/STOL aircraft. The advent of DFCS brings a tremendous capability in utilizing control surfaces and IFPC systems to provide excellent flying qualities for a V/STOL aircraft. DFCS allow computers to interpret the pilots control inputs and move the aircraft control surfaces as required to achieve the desired result. Confidence in the reliability of these systems is so high that several modern day fighter aircraft employ DFCS as the only method of aircraft control, with no mechanical backup system.

Automation of the lift system can also be a tremendous aide in reducing pilot workload during V/STOL flight. The less monitoring and manipulating of controls in the aircraft the pilot has to do, the more time he will have to devote to other mission tasks. Several capabilities are currently under investigation in this area. They include Automated Thrust Vector control, Acceleration/Deceleration controllers with velocity hold capability, height rate controls with altitude hold, and performance protection. All of these simplify the basic takeoff and landing tasks the pilot must perform. Many have argued that advances in V/STOL technology will make future V/STOL aircraft as easy to fly as conventional aircraft, but today this remains only speculation.

Although the use of a DFCS can greatly improve the capabilities of the airplane, it presents its own unique hazards. The system may be providing the pilot with exactly the response he is commanding, up to the design limits of the airplane. Traditionally, un-augmented airplanes provide some warning of approaching some limit. This might be in the form of vibrations, buffet, noise or some other clue to the pilot that he is getting close to the edge of the aircraft's flight envelope. Because a DFCS is always striving to provide the pilot with only the dynamics he is commanding, the system is working to eliminate any uncommanded aircraft motions. The result is that those cues the pilot is used to from other aircraft are either reduced or completely eliminated by the DFCS. Although these systems are usually designed to provide their own warning cues to the pilot in the forms of warning tones or displays, it is difficult to account for every possible scenario. The pilot can no longer rely on "feel" of the aircraft as an indication of aircraft's current condition. For V/STOL flight this situation could make it difficult for the pilot to sense when he is approaching the limits of the engine's performance in a heavyweight hover scenario.

Another drawback to these systems is that they may impose limits on aircraft maneuvering in order to avoid hazardous flight conditions. Unless these limits are well thought out and thoroughly tested they could unnecessarily restrict a pilot from maneuvering the airplane in certain situations. An example of this in V/STOL flight would be a limit on bank angle in a hover. If there were a 15 degree bank angle limit in the hover the pilot's ability to counter a large lateral drift might be reduced. This could be particularly dangerous during a shipboard landing. One correction to this problem

would be to raise the limit on bank angle in the hover. But if the limit is set too high, then it might not provide the protection it was intended for

Pilot Protection Features

A very important aspect of advancing V/STOL technology lies in providing the pilot with features that prevent him from getting the aircraft into a hazardous situation. Research has been conducted into providing the pilot with enhanced displays and information in the cockpit that greatly simplify many V/STOL tasks when compared to current aircraft. Incorporation of these systems into any future V/STOL aircraft should have a marked impact on the time required to train a pilot. The easier the airplane is to fly the easier it is to teach someone how to fly it. Furthermore, the easier it is to teach someone how to fly the lower the requirement for a two-seat trainer.

Several types of pilot protection features are currently being studied. There are several ways pilot protection features can be incorporated into a V/STOL aircraft. One method includes a system that limits the pilot from making control inputs that would put the airplane in a hazardous situation. Advanced displays that provide the pilot with real time hover capability information, as well as cues to fly an optimized deceleration profile to the hover is another option. Redundancy of components and backups for critical V/STOL systems are another way of increasing pilot protection.

Another approach to protecting the pilot is the use of advanced ejection seats. A system of this type was developed in the former Soviet Union and utilized in the YAK-38 and YAK-141 aircraft. In these aircraft, a loss of thrust in any of the engines could result in rapid aircraft attitude changes. The automatic ejection system activated if certain

limits of aircraft attitude, angular acceleration, and/or rate of descent were reached. The system was armed when the thrust vector was rotated beyond a certain limit.

One of the more difficult aspects of flying the AV-8B is the need for the pilot to always be aware of the performance capability of his aircraft. The aircraft will allow the pilot to slow down to an airspeed at which the engine cannot provide enough thrust to support the weight of the aircraft. To prevent this, a feature that prevents the pilot from selecting a thrust vector angle that would result in a deceleration to an unsafe speed is being studied.

A variety of these pilot protection features have showed success in simulation and flight test but have not been proven in operational aircraft. If successful, features of this type could reduce the need for close instructor supervision in the V/STOL environment. This would greatly reduce the requirement for two seat trainers. The complexity of future V/STOL aircraft, however, presents significant challenges to developing protection features that cover all scenarios but do not unnecessarily limit the pilot. The requirement for close supervision will remain until these protection features have demonstrated their effectiveness.

VAAC Research

A recent flight test program in the United Kingdom utilized the VAAC aircraft to study a variety of V/STOL control schemes. The goal of this research was to find a solution for a V/STOL control scheme that would work for all V/STOL tasks. Nine pilots of different experience levels and backgrounds took part in this research. Five of

the pilots had previous V/STOL experience and the remaining four had none. The pilots were asked to perform three maneuvers:

1. Approach to hover,
2. Translation to hover pad, and
3. Vertical landing

For each of these maneuvers, the pilots were asked to assign a Handling Qualities Rating (HQR) to the aircraft for that task. The Cooper-Harper rating scale shown in Figure A-11 was utilized. Three advanced V/STOL control schemes were compared to the basic Harrier flight control set up. The results for the approach to hover task are shown in Figure 5-1.

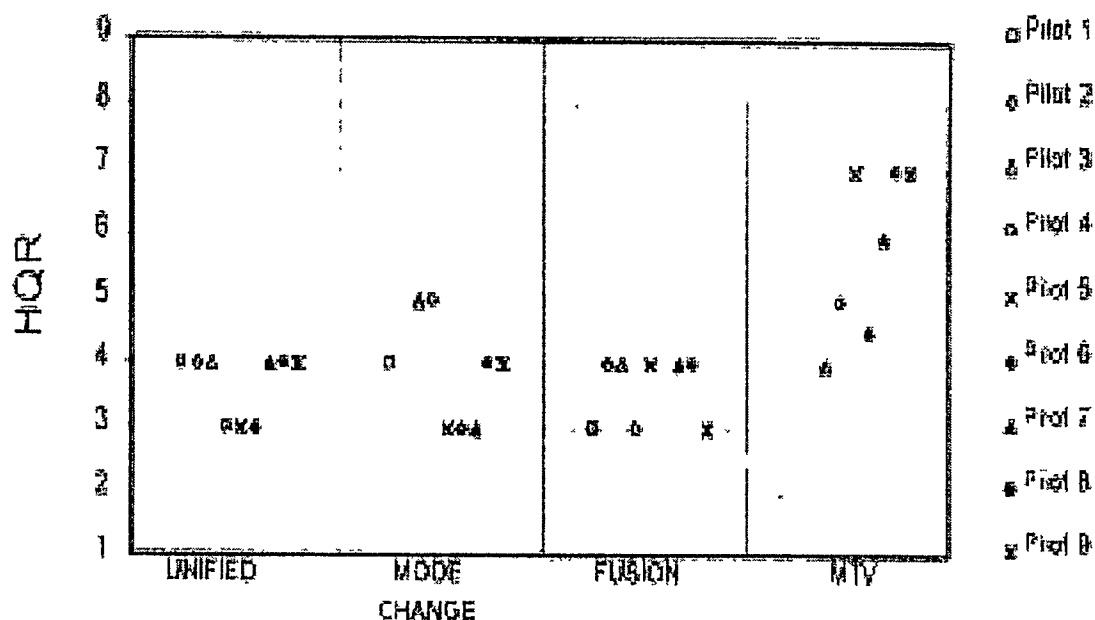


FIGURE 5-1 APPROACH TO HOVER RATINGS

SOURCE: VAAC Flight Trial Results, Parnes, J, Aug 99

The other tasks also showed that the majority of pilots' preferred one of the advanced modes to the basic Harrier mode. Although the ratings were generally better for the advanced modes, they each had discrepancies which were noted by the pilots and which affected their ratings. These discrepancies included mechanical characteristics of the control inceptors and the tendency toward cognitive errors. If the flight control scheme is not intuitive, cognitive errors are more likely to occur.

CHAPTER VI

RISK MITIGATION THROUGH USE OF TWO SEAT TRAINERS

Two seat trainers provide risk mitigation on several levels. If eliminated, the risk that new pilots face during initial V/STOL training will increase. As the pilot gains more experience with an aircraft, his/her chances of having a mishap tend to decrease. Figure 6-1 shows the mishap trends, based on pilot experience, for the AV-8B Harrier. As shown, the pilot is most susceptible to mishaps in the first 200 hours of flying. It is essential that the proper flying techniques, required to fly the aircraft, be developed in initial training. This is easily accomplished with the use of two seat trainers.

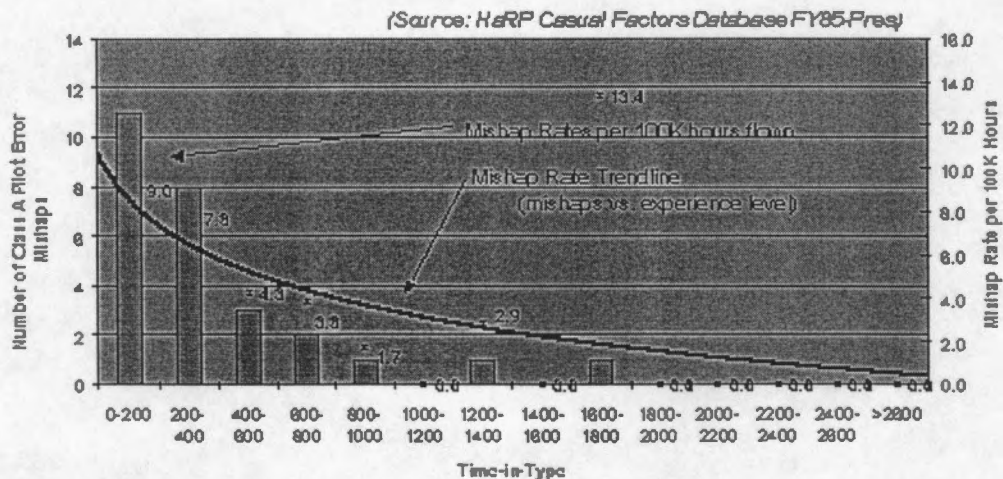


FIGURE 6-1 MISHAPS AS A FUNCTION OF PILOT EXPERIENCE

Source: HaRP Causal Factors Database FY85-98, First Annual Report 1998

If two seat trainers were not available, it would leave two other methods for teaching the student the proper techniques of V/STOL flight. The first would be the use of a simulator, with an instructor seated at the control station. The instructor could talk the student through maneuvers or tasks as well as monitor the student's performance via the information displayed at his console. The instructor could observe pertinent flight parameters, magnitude and frequency of control inputs, and aircraft status from the console. This method has proven highly effective for initial development of proper procedures for a new aircraft. However, the benefits to teaching proper techniques and skills are very dependent on the simulator's fidelity.

The second option is to have the student fly solo in the aircraft while the instructor monitors from a remote location. This could be accomplished in several ways, each of which has its own limitations. One would be to place the instructor on the ground in a place to observe the student's take-off and landing. This method only allows the instructor to observe aircraft behavior. He must guess at the student's flight control inputs and technique based on his own experiences. The instructor can only offer voice commands to the student to aid in technique refinement or to correct a hazardous situation.

Another option is to place the instructor in an aircraft and have him fly formation, or "chase", the student on his solo flights. The instructor has about the same capabilities as the ground instructor, except that he can go anywhere the student goes, and better guess at control inputs based on what he has to do in his own cockpit to stay in formation with the student's aircraft. This method has some limitations that include

1. Instructor can only observe the aircraft response, not the student's control inputs,
2. Instructor has to maintain control of his own aircraft while observing the student,
3. Instructor can only interact with the student via radio,
4. With only voice communications, a delayed response in an emergency situation is inevitable, and
5. For each of these sorties, two aircraft are required.

Use of a two-seat trainer avoids all of these limitations. The instructor has immediate insight into the student's technique and can offer pertinent and timely feedback. The instructor is also in a position to quickly correct mistakes, by taking control of the aircraft, before they become dangerous situations. The only significant drawback to a two-seat trainer is cost of development. Production and operating costs should be about equal to that of the single seat airplane. Although the initial development costs may be substantial they must be weighed against the costs of other training options and the potential savings in reducing mishaps.

Task Training Survey

In a recent study to determine requirements for future pilot training, a survey was conducted amongst a group of pilots with various backgrounds. Questions were posed regarding the requirement for instructor pilot intervention during the performance of certain tasks. The choices were no instructor intervention, delayed intervention and immediate intervention required. Delayed intervention referred to an instructor being

able to critique the student's performance after the flight or tasks were complete. Immediate instructor intervention had two levels, remote and on site. The difference between on site and remote intervention was that the on site instructor could physically take control of the aircraft whereas the remote instructor could only verbally instruct the student what to do. A small portion of the results of that survey is provided in table 6-1. The responses selected were from AV-8B pilots with some level of instructor experience as well. The task list included Short takeoff, Vertical takeoff, Vertical landing, and Slow Landing as well as ten other V/STOL unique items. The results clearly show the majority of those surveyed felt that on site instructor intervention was necessary for the spectrum of tasks presented.

TABLE 6-1 SURVEY RESULTS¹³

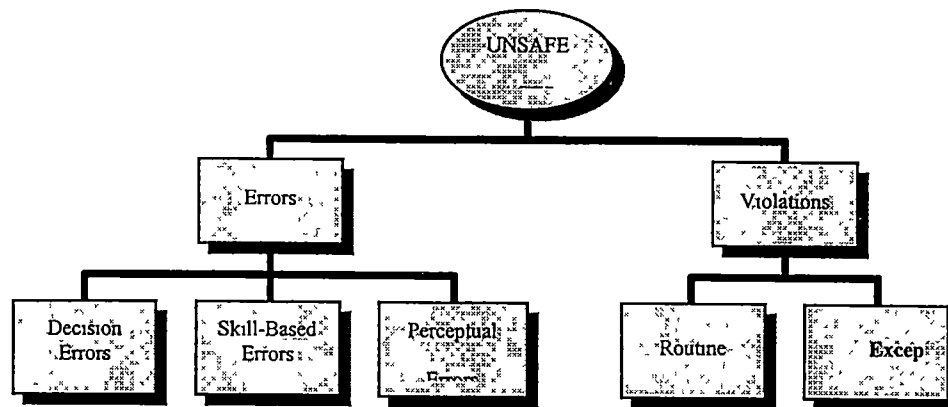
Instructor Pilot Intervention	Percentage response
Immediate, On site	74
Immediate, Remote	14
Delayed	11
N/A	1

In order to prevent or reduce mishaps through effective training the causes of mishaps must be understood. Figure 6-2 is a diagram that shows the potential sources of pilot related mishaps. Violations are not typically remedied through training; they are a function of pilot discipline and supervision. The sources of errors, however, are affected by training. Effective training can help a pilot develop proper skills and provide the knowledge to make correct decisions. In a two-seat trainer, the instructor pilot can pass

along to the student techniques and decision criteria that have been refined with years of experience. Perceptual errors can be mitigated if the training the pilot has undergone training in a realistic environment.

FIGURE 6-2 SOURCES OF UNSAFE ACTS

Source: *HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS) A*



Human Error Approach to Accident Investigation OPNAV 3750 6R (Appendix O)

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Reducing time to train is a goal of all aircraft programs. This can be accomplished in a variety of ways as long as the final result is safe and effective training. V/STOL flight presents many unique challenges that make reducing time to train a difficult task. These challenges are directly related to the environment a V/STOL aircraft operates in, the tasks it performs, and the design features that provide its V/STOL capability. Future V/STOL aircraft will be required not only to meet, but also to exceed the capabilities of those currently in service. Advances in these capabilities will come with an increase in complexity of the aircraft. Training pilots to operate these complex aircraft will continue to be important not only for combat effectiveness but also for safety and preservation of assets.

This report has shown that the high fidelity required to model the V/STOL flight regime is not easily achievable in flight simulators. The low frequency, large displacement motions associated with V/STOL jetborne flight, require extensive motion systems. Large projection screens or domed enclosures are necessary to provide realistic visual scenes and field of view. If these issues can be resolved, then extensive testing of the aircraft and the simulator is required to ensure their characteristic match as closely as possible. Once these requirements have been achieved, consideration can be given to abandoning two seat V/STOL trainers in lieu of high fidelity flight simulators. It is

unlikely, however, that these high fidelity simulators will be an option for the next V/STOL aircraft.

The Harrier is the only V/STOL aircraft currently in operational service. It has an accident rate that exceeds other tactical jets currently in service. This is attributed in part to the difficulty of operating the aircraft. Advances in technology continue that should produce V/STOL aircraft that are easier to fly than the Harrier. Despite these advances, the pilot will be challenged with V/STOL flight controls that may be unique in configuration as well as functionality. The functionality of these flight controls may change during transitions from conventional to V/STOL flight. Very little in the pilot's previous flight training will have prepared him for this situation.

Along with the uniqueness of the aircraft, the pilot will be exposed to completely new tasks for takeoff and landing. Once again, his previous training will not provide the requisite skills required to safely and effectively perform these tasks. If no two-seat V/STOL trainer is available, the pilot will be forced to rely on skills and techniques developed in a flight simulator that may not be truly representative. Additionally, advances in technology will bring advances in V/STOL capability. As capability increases, the desire to utilize that capability for more challenging tasks will emerge. This may lead to performing V/STOL tasks in more severe weather conditions or to more austere locations than are the standard today.

Despite technological advances, the hazards of operating in the V/STOL environment will remain constant. The aircraft will routinely be operated in close proximity to the ground and at very slow airspeeds. Pilots will need to be able to rapidly

ascertain when a deteriorating condition is occurring, as well as make quick decisions to respond to this situation. The ability to recognize and react to these dangerous situations will come only with experience. For a new pilot, it would be much safer to achieve some of this experience in a two seat aircraft with an instructor pilot on board. This would allow the student to receive feedback, direction, and intervention from the instructor as necessary.

The utility of a two-seat trainer is not limited to new student training. A large number of the first pilots assigned to a new aircraft will be experienced pilots that make the transition from other aircraft types. This will most certainly include Harrier pilots who will bring some measure of V/STOL experience with them. However, along with their experience, these pilots bring habit patterns. It is likely that some of their habit patterns from the Harrier won't apply to the new V/STOL aircraft. Some habit patterns may even be dangerous in the new aircraft. Errors where the pilot uses techniques or procedures developed in other aircraft are called reversion to type errors. It is possible that reversion to type failures could lead to aircraft mishaps. A large number of crashes attributable to reversion to type pilot errors would be disastrous for a new V/STOL aircraft in its first years of operation.

The advantages offered by a two-seat V/STOL trainer in terms of safety and training effectiveness should outweigh the disadvantages of development and operating costs. The training benefits not only new students to V/STOL but experienced V/STOL pilots that make the transition from the Harrier. The two-seat variant need not be limited to the training role. Several two-seat aircraft variants provide combat mission capability

as well as a training capability. This allows the two-seat variant to deploy with a combat squadron and provide an asset for continued pilot training in places where no simulator is available.

The ideal solution is to develop a two-seat variant of any future V/STOL aircraft that is combat mission capable. This is by far the best option to ensure safe and effective training as well as multi-role utility of the two-seat variant. If development of a two seat variant for future V/STOL aircraft is not fiscally or technically feasible, then the following options are offered to meet the requirement for a two seat V/STOL trainer:

- 1 Develop a limited number of two seat variants, with minimal or no combat capabilities, that are used exclusively as trainers.
- 2 Produce new TAV-8Bs that can as closely as possible emulate the new V/STOL aircraft and it's handling qualities. Other advances and upgrades should be included to give these aircraft as much combat capability as possible without degrading the ability to function as a trainer. Incorporation of a DFCS has been successfully demonstrated in the VAAC aircraft, which is basically a TAV-8A aircraft. At a minimum, this would provide pilots with exposure to the V/STOL environment, an introduction to the unique aspects of V/STOL aircraft, and an introduction to unique V/STOL tasks under close instructor supervision.
- 3 Develop a life extension program for existing TAV-8Bs and incorporate a DFCS that uses similar control strategy as the new V/STOL aircraft.

4. Maintain current TAV-8Bs to serve as basic V/STOL environment trainers

These aircraft could be utilized to provide aircrew with initial exposure to V/STOL tasks and the environment. Although the TAV-8B may differ greatly from any future V/STOL aircraft, the benefits of close instructor supervision during initial exposure to the unique aspects of V/STOL flight would be beneficial.

5. Accept the risks associated with elimination of a two-seat trainer and develop a training method for initial V/STOL flights in the new aircraft that provides as much instructor supervision as possible. This should include, at a minimum, ground based observation of the student's takeoff and landings. Explore the use of virtual reality and data link technology which could provide the ground based instructor insight to control inputs and condition of the student's aircraft. This would allow the instructor the benefits of providing immediate pertinent feedback as well as remotely flying the aircraft from his ground location.

The author does not consider option number five above to be safe or effective. It is also limited by virtual reality and data link technology that has yet to mature to a high enough level. Basic flying skills have been and should continue to be taught under the close supervision of an experienced instructor pilot. No one would consider letting a pilot attempt his first landing in a jet aircraft by himself, having only practiced the landing in a less than optimal flight simulator. A similar example of a student helicopter

pilot attempting his first hover or vertical landing can be used. The same common sense that sees these ideas are unsafe should be applied to V/STOL training. The unique aspects of V/STOL flight demand a highly effective training method. The most reasonable solution to provide this level of training remains a two seat aircraft.

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APPENDIX

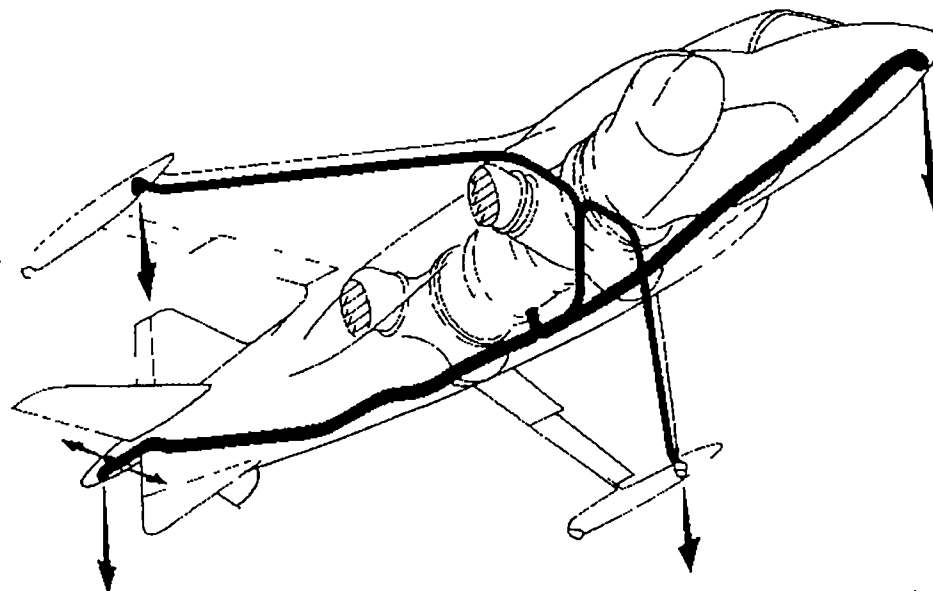


FIGURE A-1 HARRIER REACTION CONTROL SYSTEM

Source: *The British Aerospace Harrier: A Case Study in Aircraft Design*, Fozard, J. July 1978

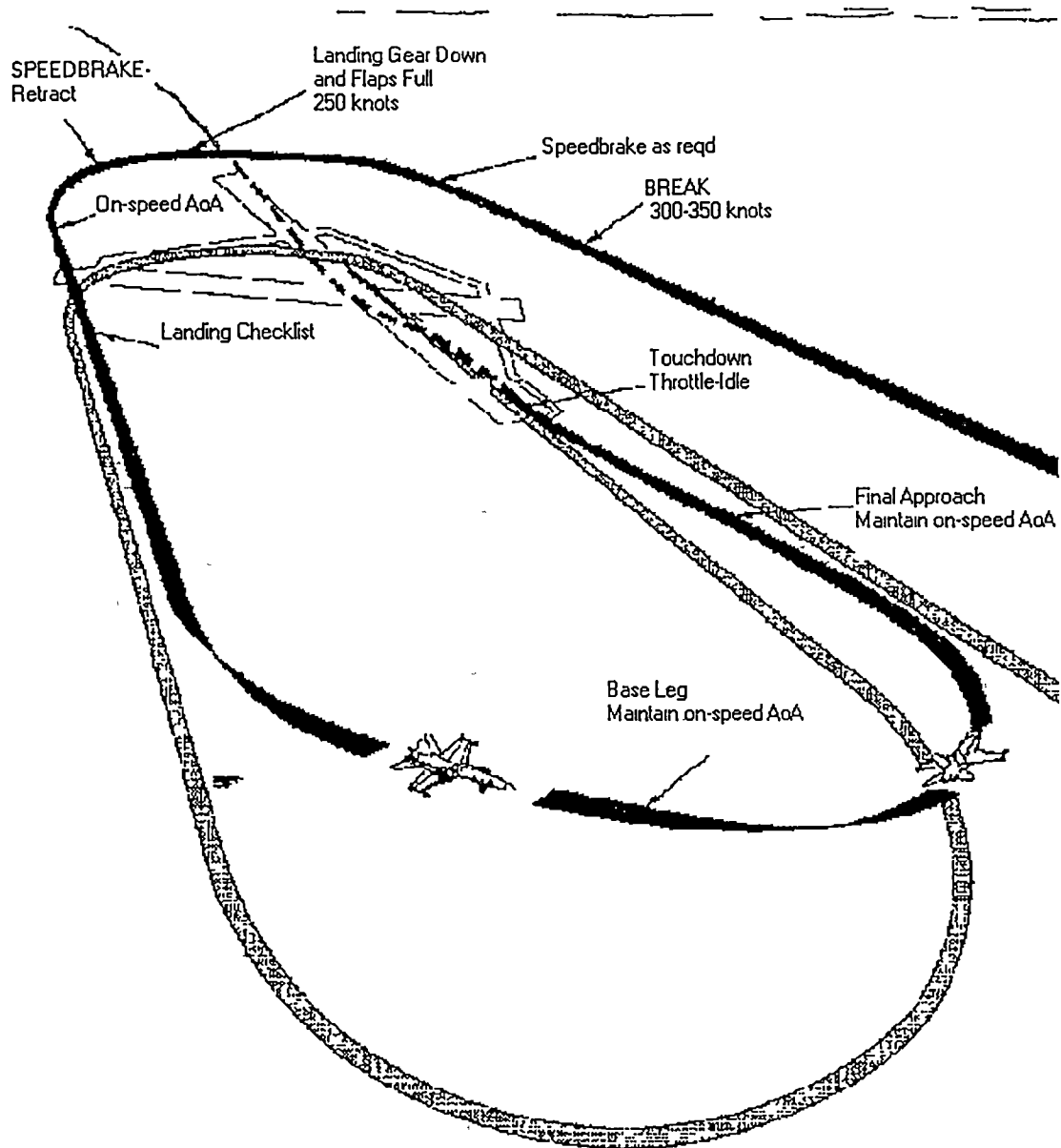


FIGURE A-2 CONVENTIONAL AIRCRAFT LANDING

Source *NATOPS FLIGHT MANUAL NAVY MODEL F/A-18* August 1995

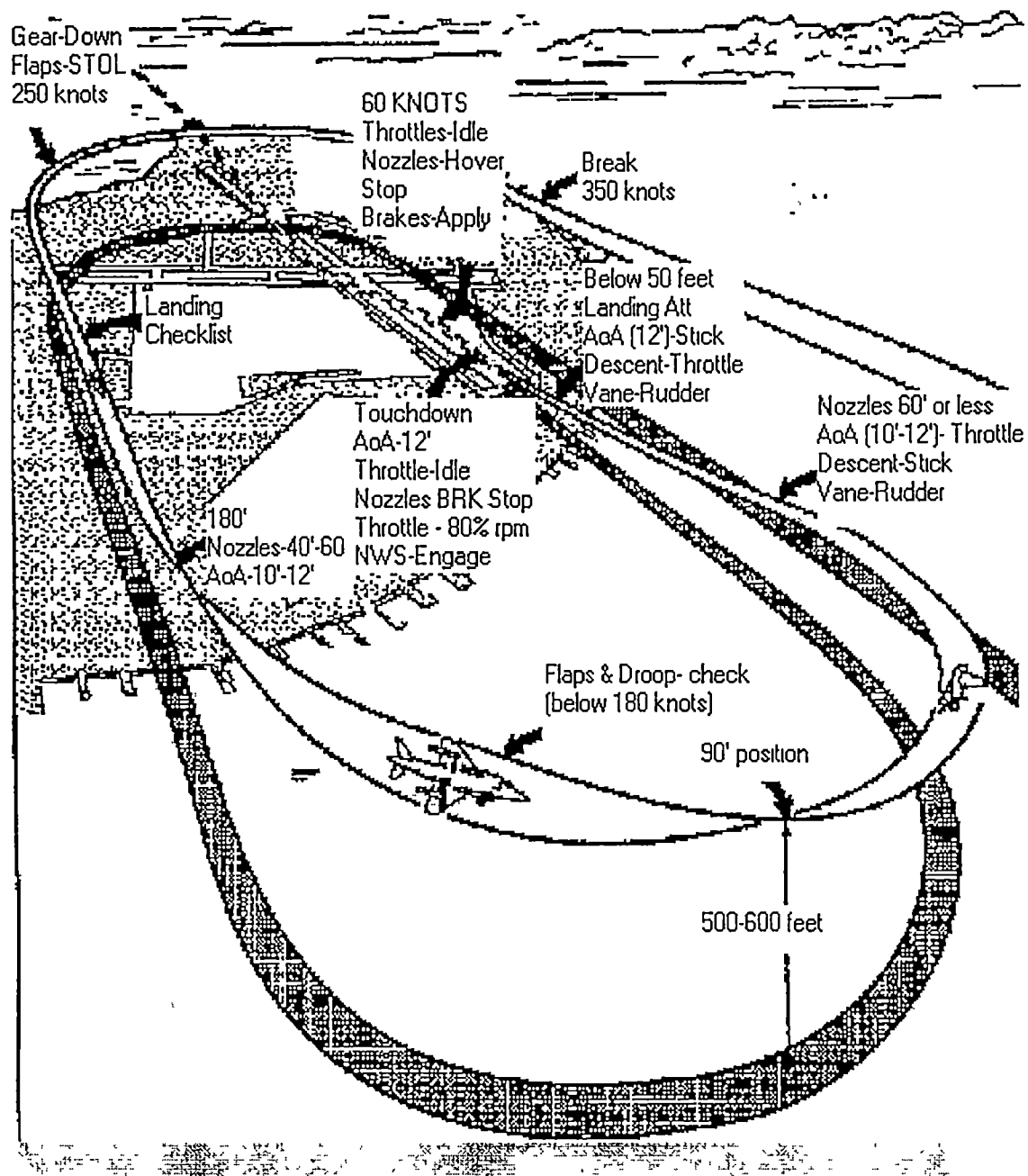


FIGURE A-3 HARRIER SLOW LANDING

Source *NATOPS FLIGHT MANUAL NAVY MODEL AV-8B A1-AV8BB-NFM-000 1*
August 1995

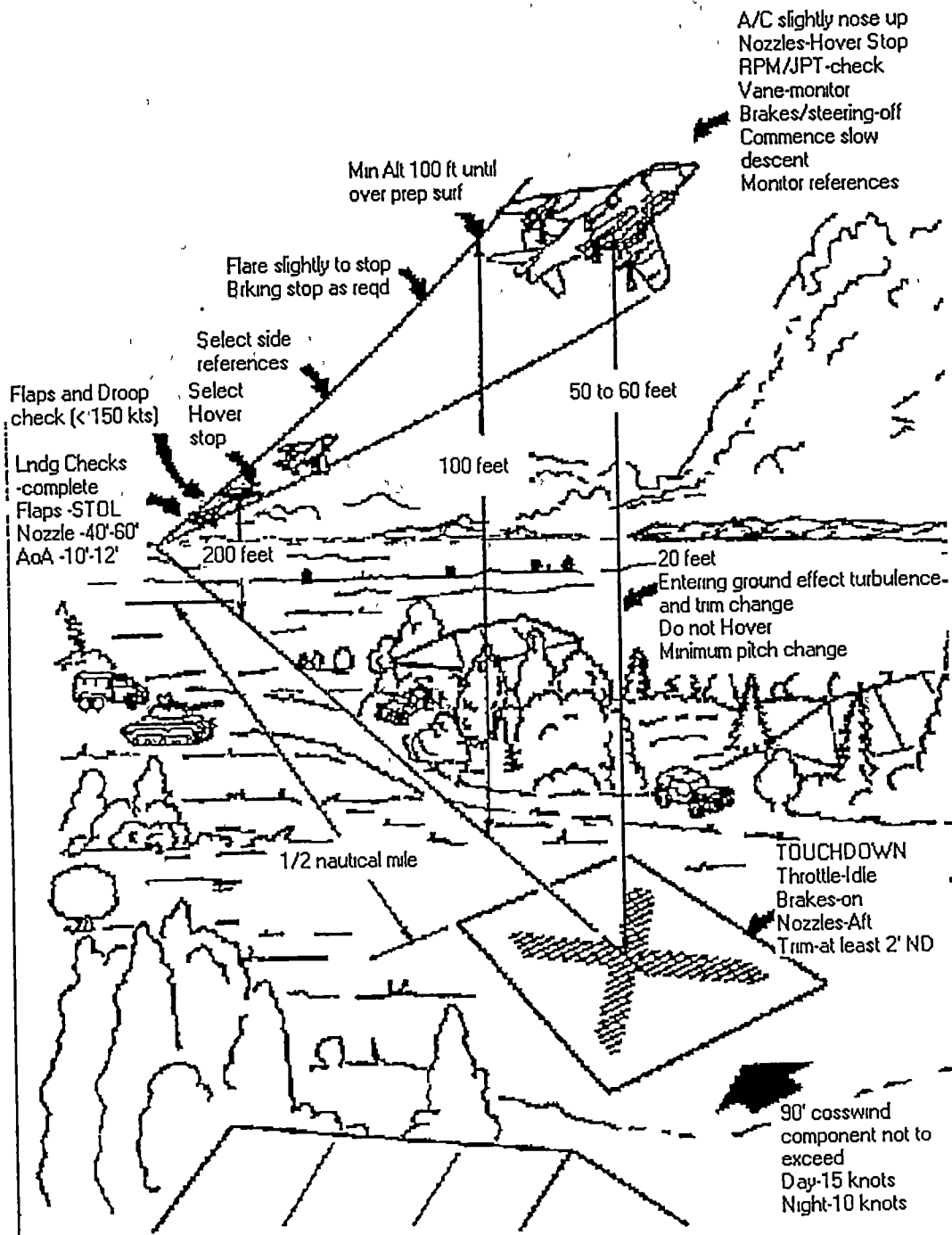


FIGURE A-4 HARRIER VERTICAL LANDING

Source. NATOPS FLIGHT MANUAL NAVY MODEL AV-8B A1-AV8BB-NFM-000 1
August 1995

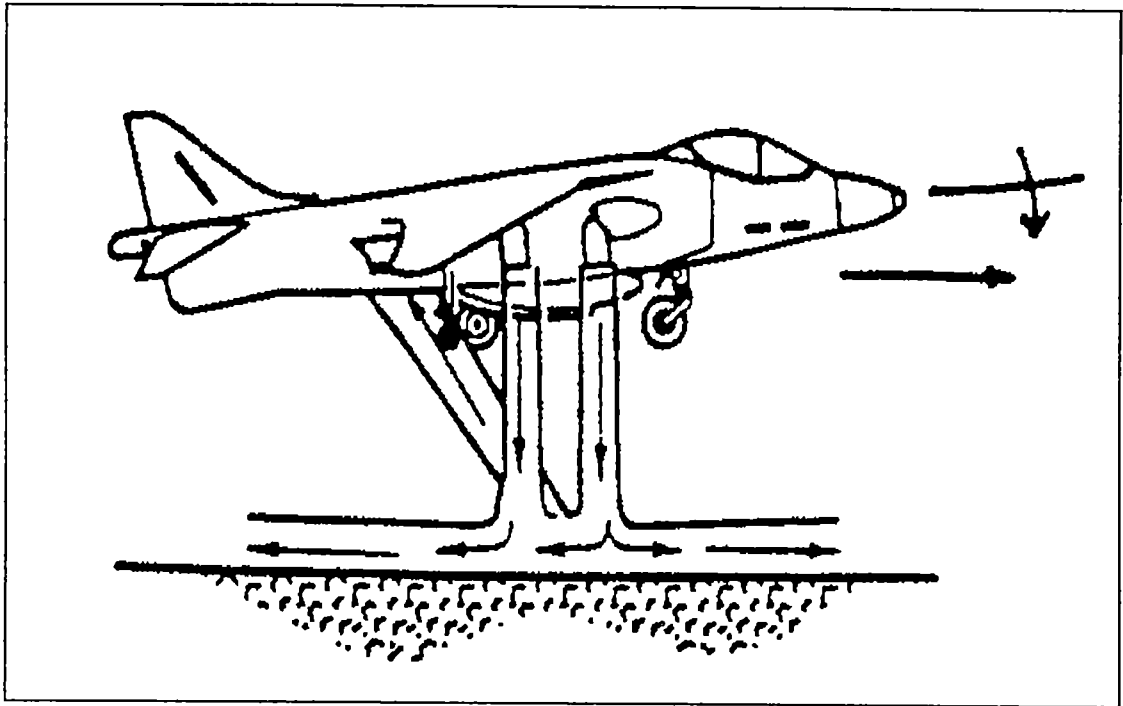


FIGURE A-5 HARRIER JET INDUCED EFFECTS IN PITCH

Source *NATOPS FLIGHT MANUAL NAVY MODEL AV-8B* A1-AV8BB-NFM-000 1
August 1995

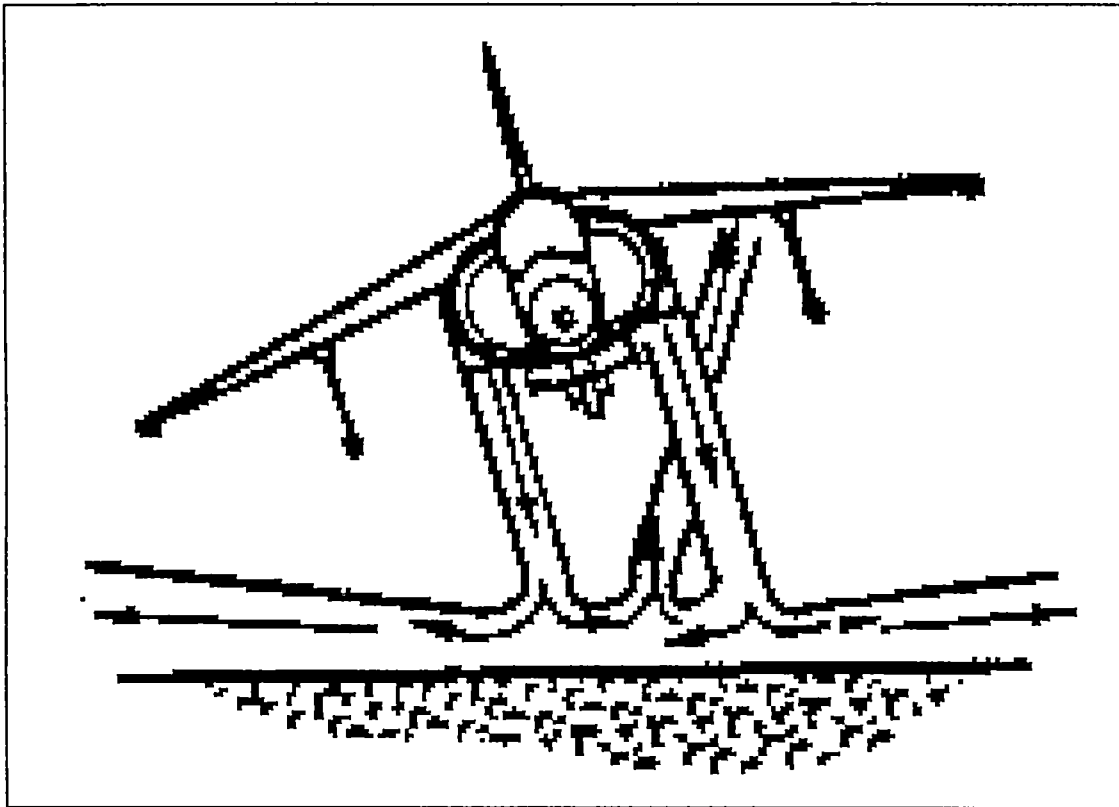


FIGURE A-6 HARRIER JET INDUCED EFFECTS IN ROLL

Source *NATOPS FLIGHT MANUAL NAVY MODEL AV-8B* A1-AV8BB-NFM-000 1

August 1995

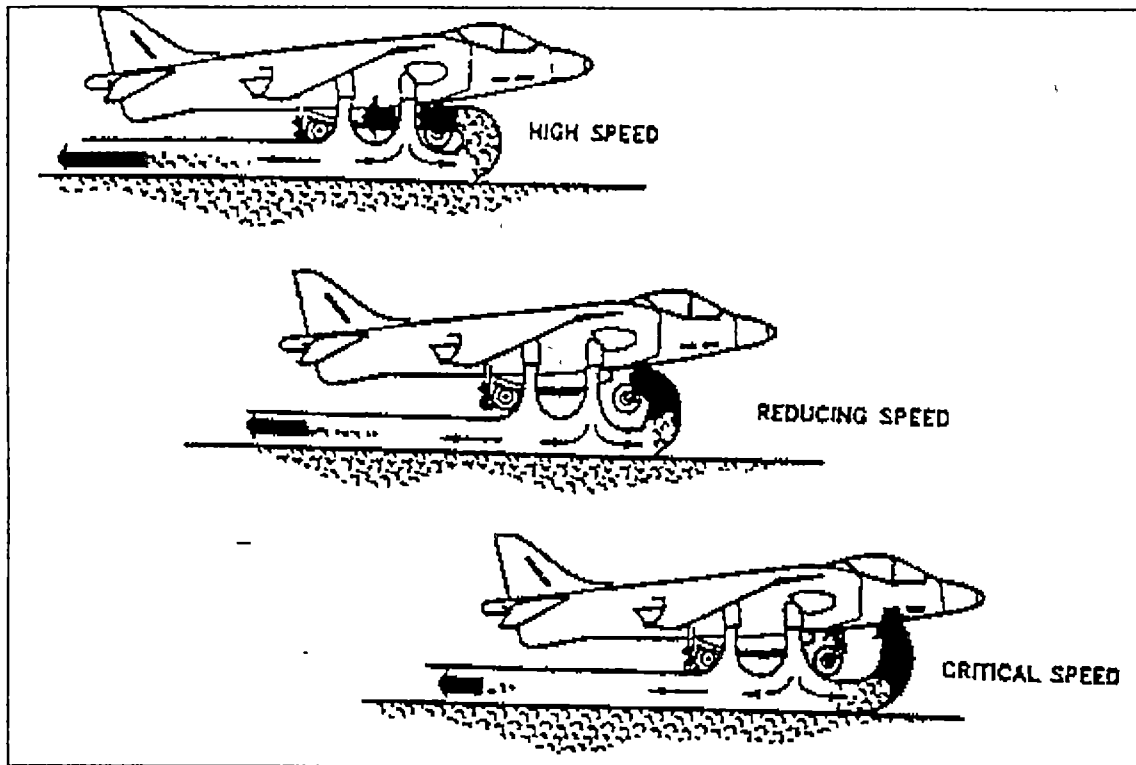


FIGURE A-7 HARRIER HOT AIR AND FOD REINGESTION

Source *NATOPS FLIGHT MANUAL NAVY MODEL AV-8B A1-AV8BB-NFM-000 1*

August 1995

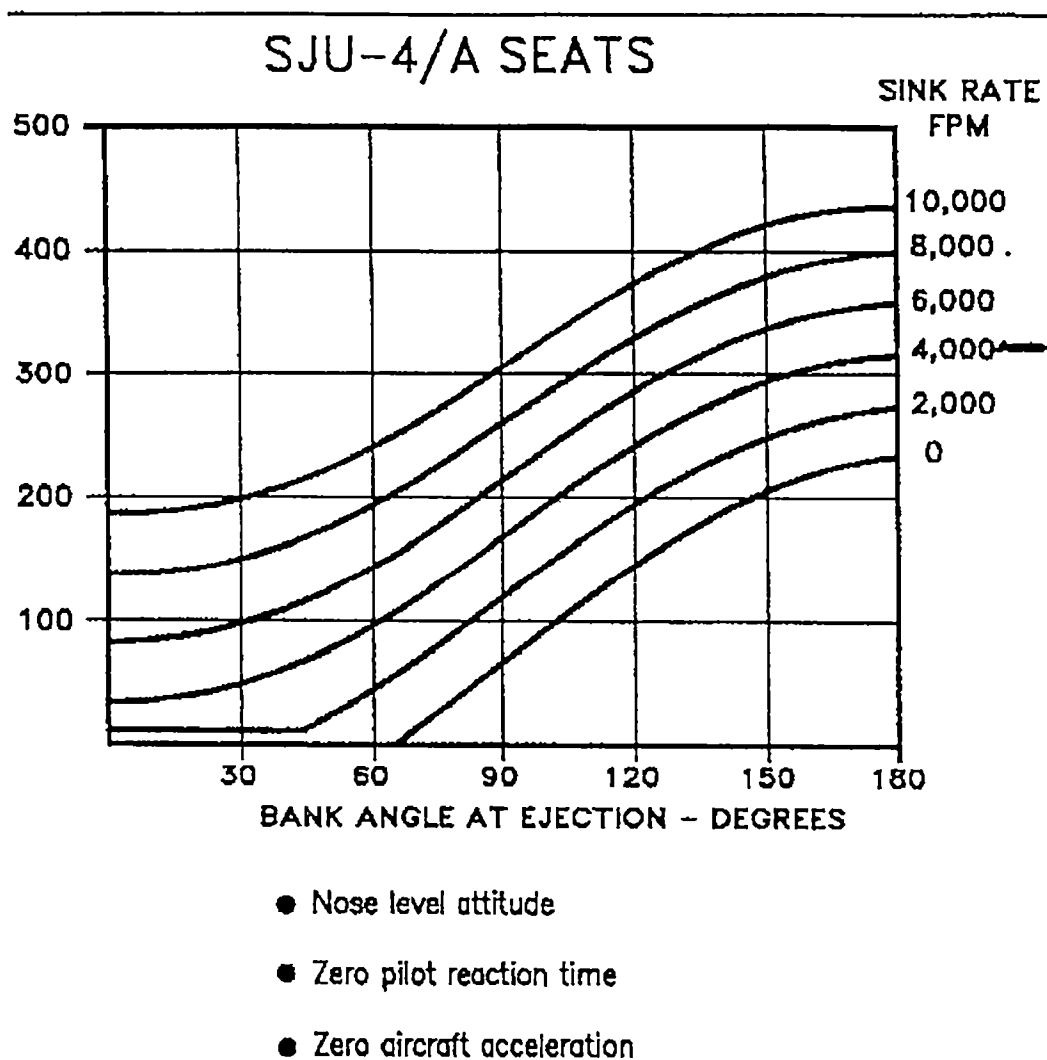


FIGURE A-8 HARRIER EJECTION SEAT ENVELOPE

Source. *NATOPS FLIGHT MANUAL NAVY MODEL AV-8B A1-AV8BB-NFM-000 1*

August 1995

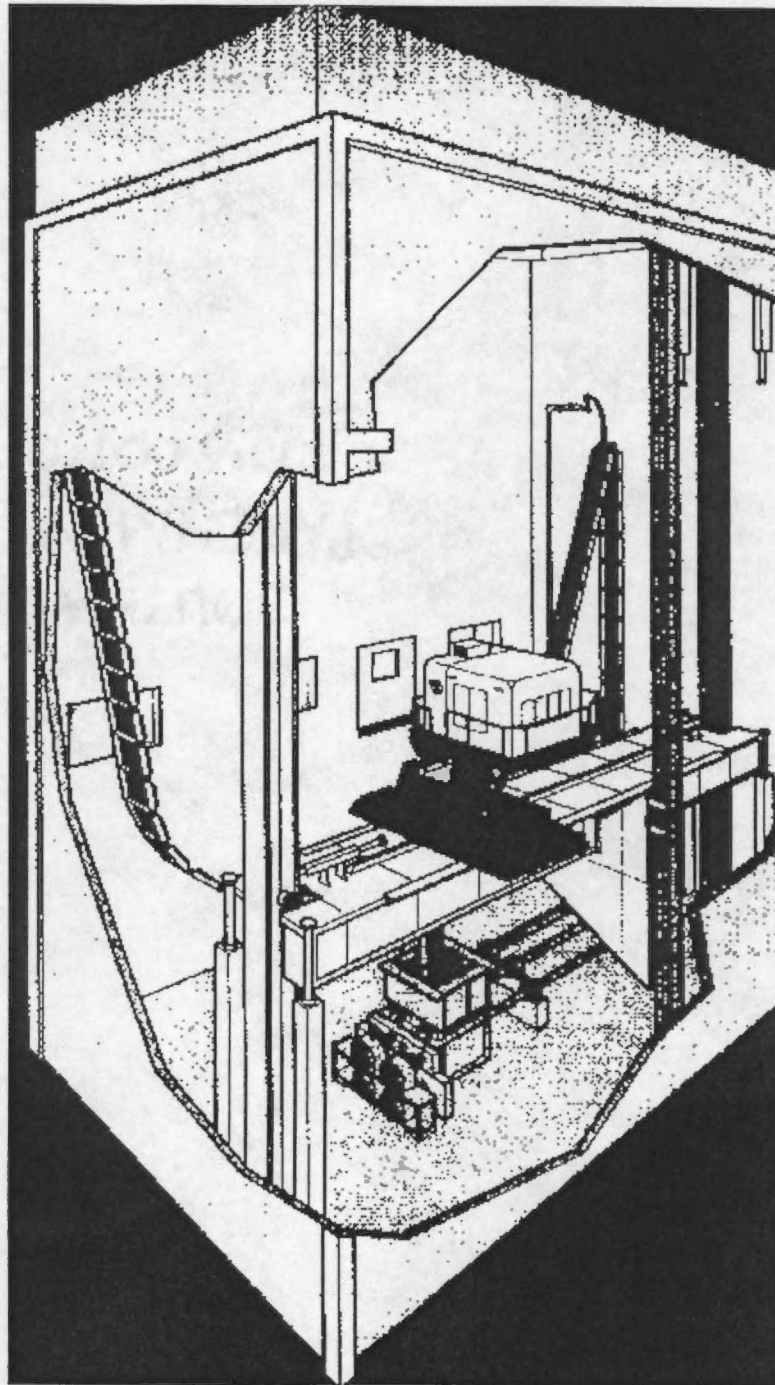


FIGURE A-9 NASA AMES VERTICAL MOTION SIMULATOR

Source: *NATOPS FLIGHT MANUAL NAVY MODEL AV-8B A1-AV8BB-NFM-000 1*

August 1995

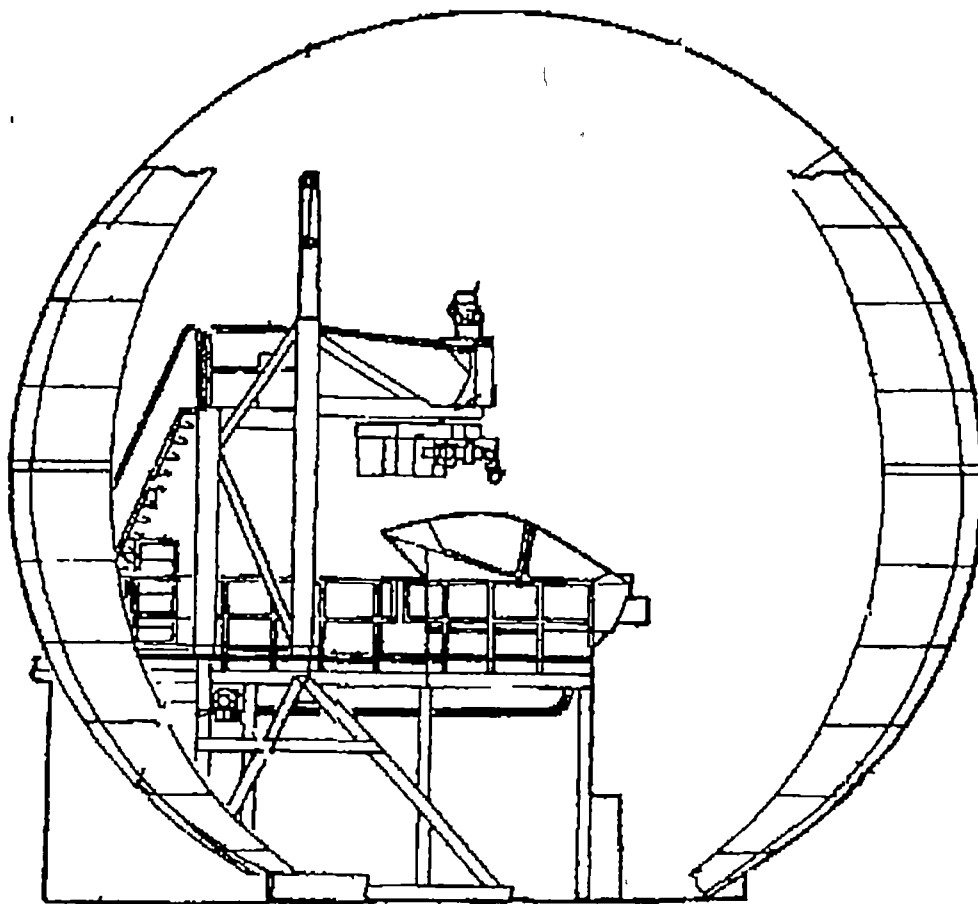


FIGURE A-10 HARRIER RADAR NIGHT ATTACK SIMULATOR

Source: *NATOPS FLIGHT MANUAL NAVY MODEL AV-8B* A1-AV8BB-NFM-000 1

August 1995

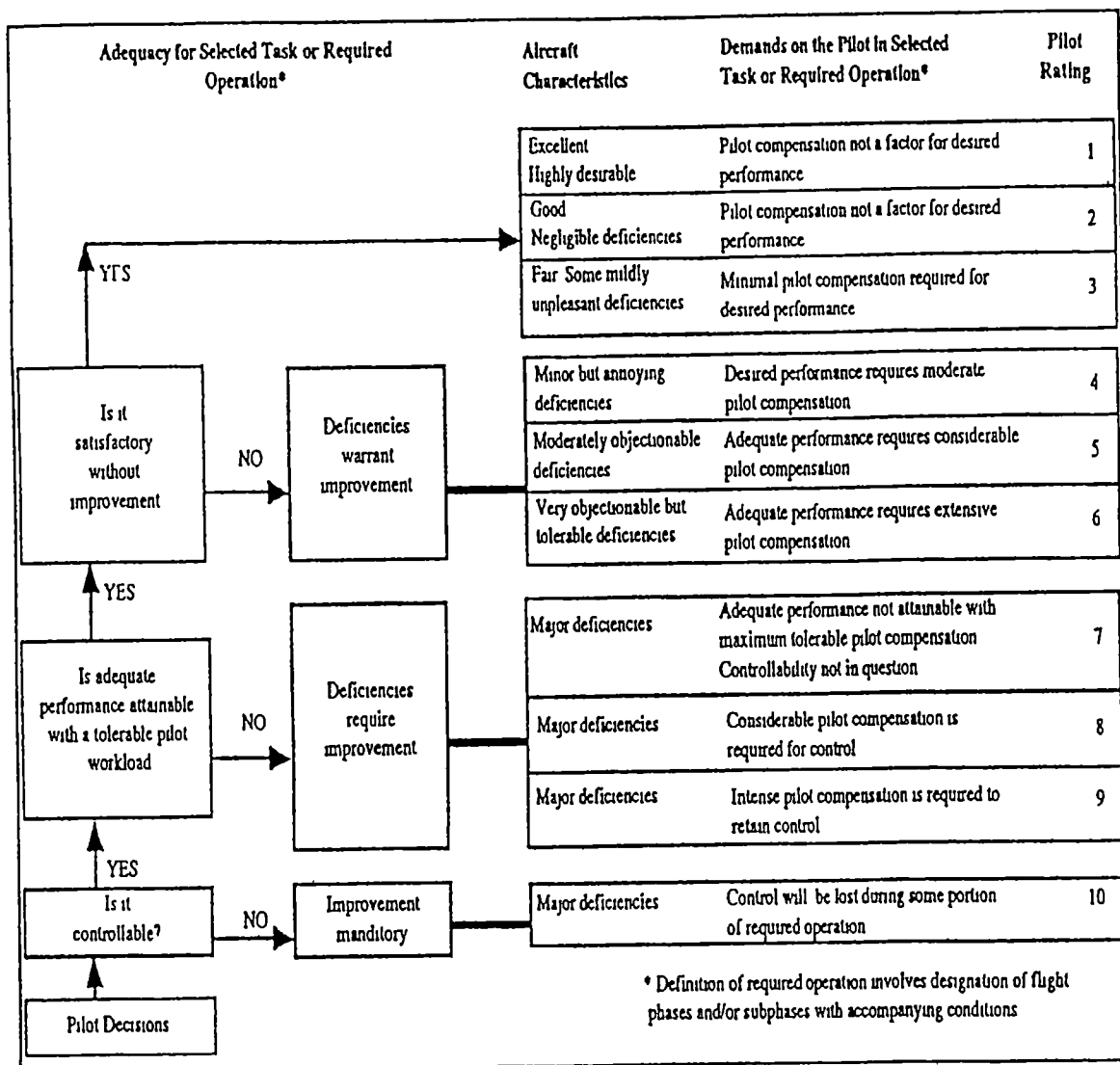


FIGURE A-11 COOPER HARPER RATING SCALE

VITA

Major Arthur Tomassetti was born in Port Chester, New York on March 13 1964. He attended elementary schools in New York and Florida and graduated from St. Thomas Aquinas High School in 1982. In 1986 he received a Bachelor of Science Degree in Mechanical Engineering from Northwestern University and was commissioned as a Second Lieutenant in the United States Marine Corps. After completing The Basic School in Quantico, Virginia he entered Flight Training. He was designated a Naval Aviator in October of 1988 and began Harrier Flight Training. Major Tomassetti has served with two Fleet squadrons and his billets include Standardization Officer, Weapons and Tactics Instructor, and Operations Officer. Major Tomassetti graduated from the US Navy Test Pilot School in 1996. Maj Tomassetti has over 2200 of flight time, more than 1500 of which is in the AV-8B Harrier, and has flown more than 25 different types of aircraft.

He is currently serving as a member of the Joint Strike Fighter Joint Test Force and has been assigned to the Lockheed Martin X-35 test team. Major Tomassetti's awards include the Air Medal with Valor device and numeral 3 for combat missions flown during Operation Desert Storm, The Navy Commendation Medal, and the Navy Achievement Medal. Maj Tomassetti is married to the former Marchelle Gingrich of Yuma, Arizona and has one daughter.